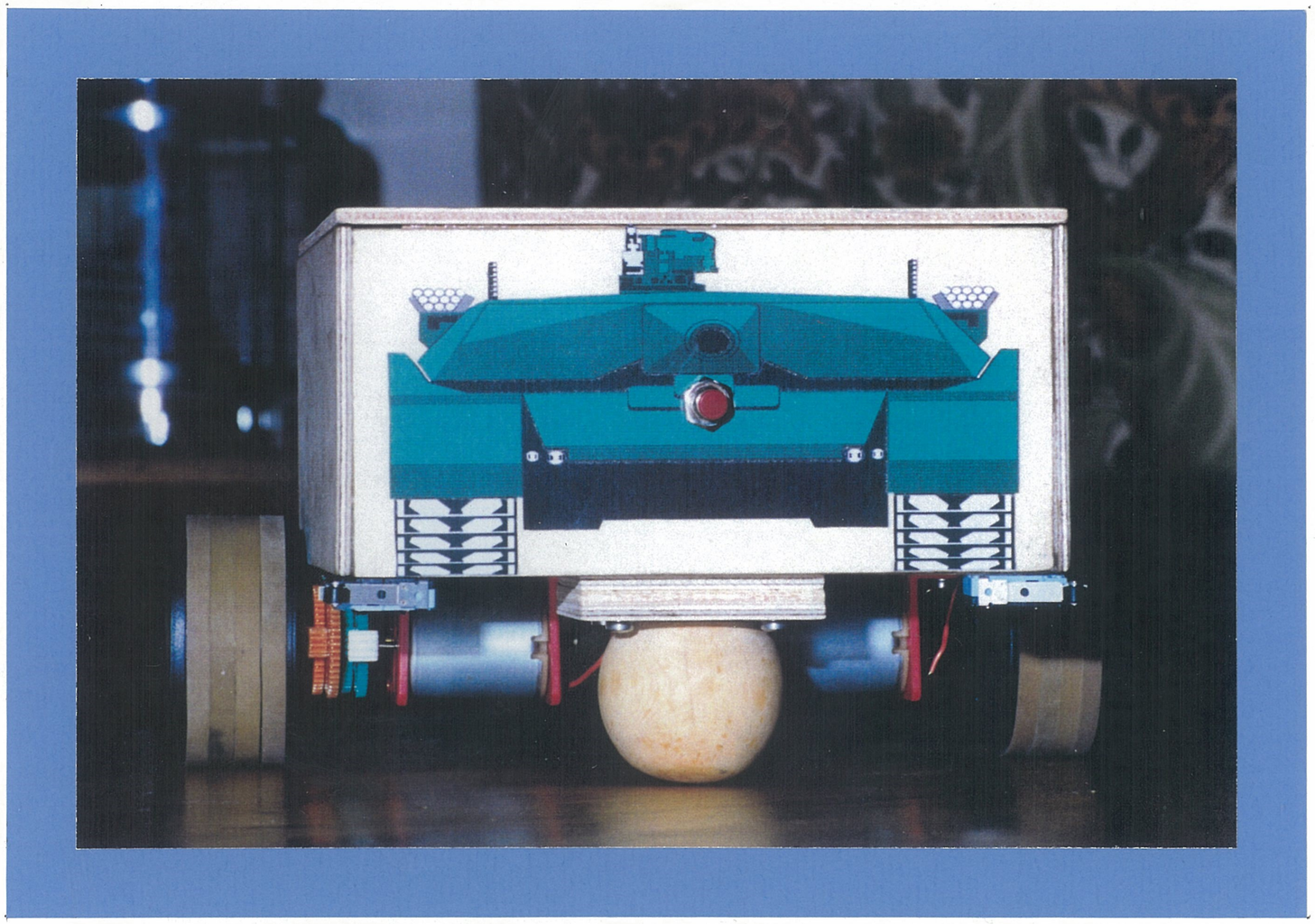


Final Product

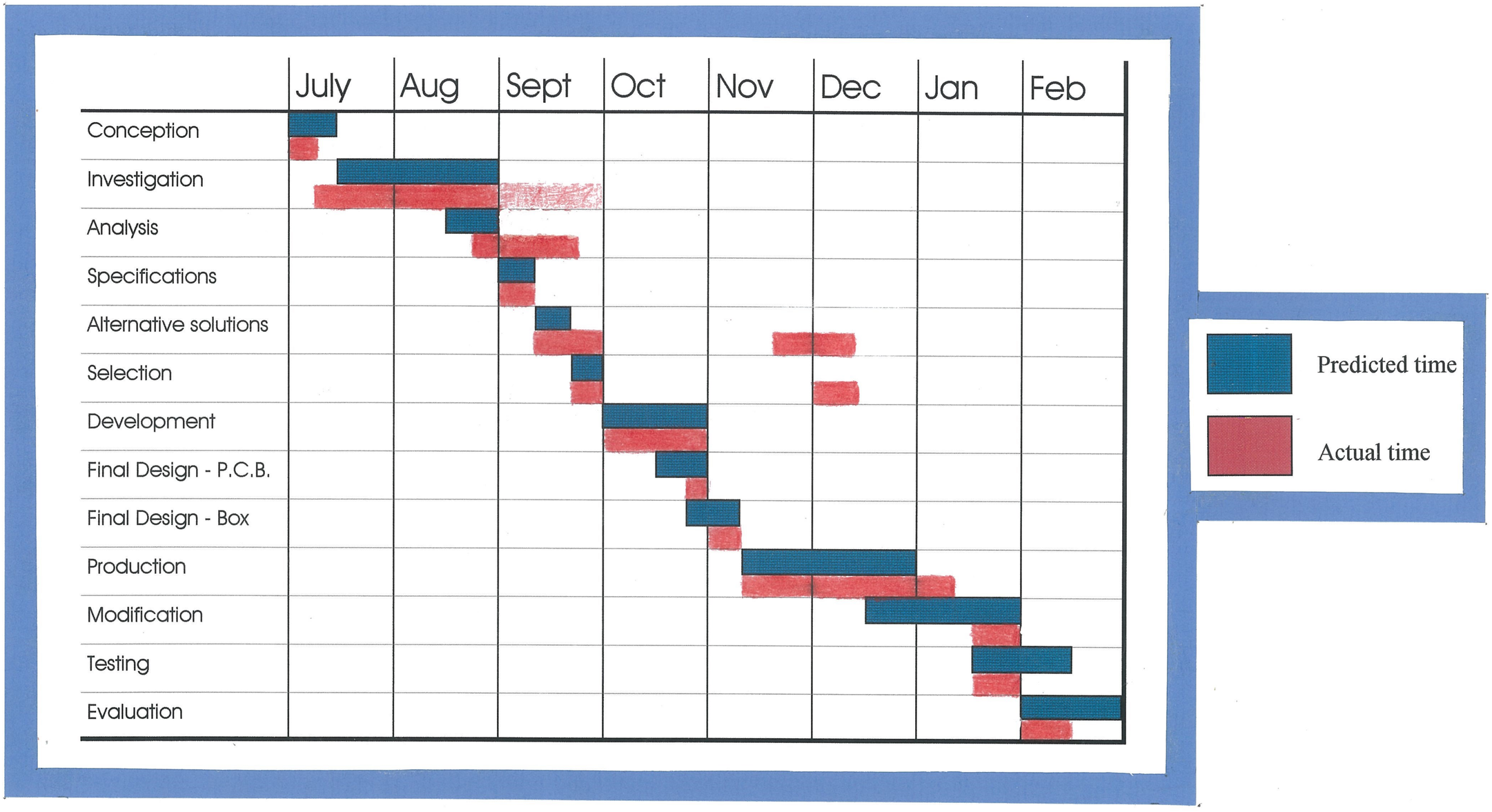
Statement of Need

Toys are needed by all ages to pass the time in an amusing way. Theses range from toddlers' toys to executive toys. I have an 8 year old niece who is frequently bored by her wealth of traditional toys associated with her age and sex.

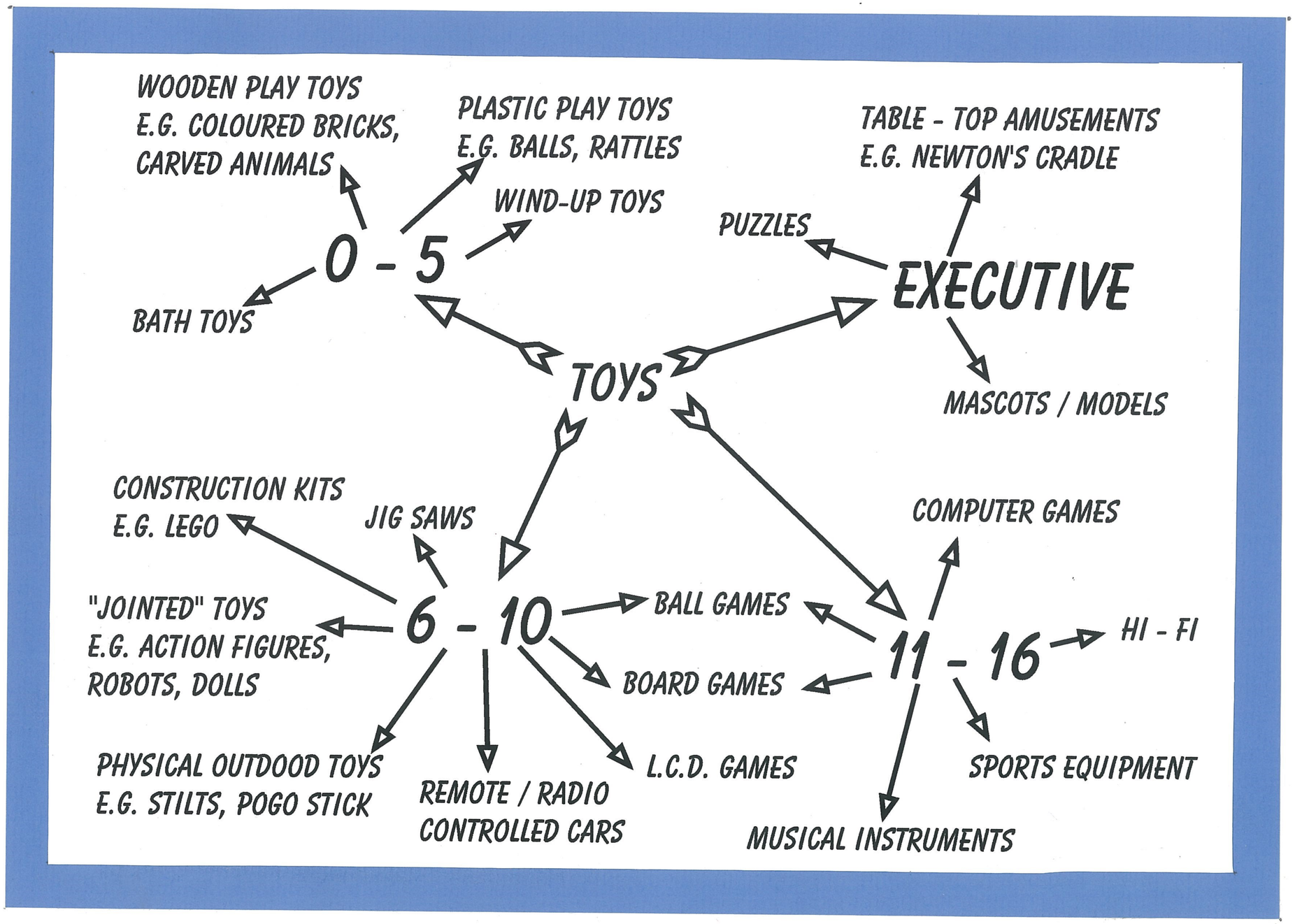
Design Brief

To design and construct a toy which is affordable, amusing and will occupy a young child for long periods of time.

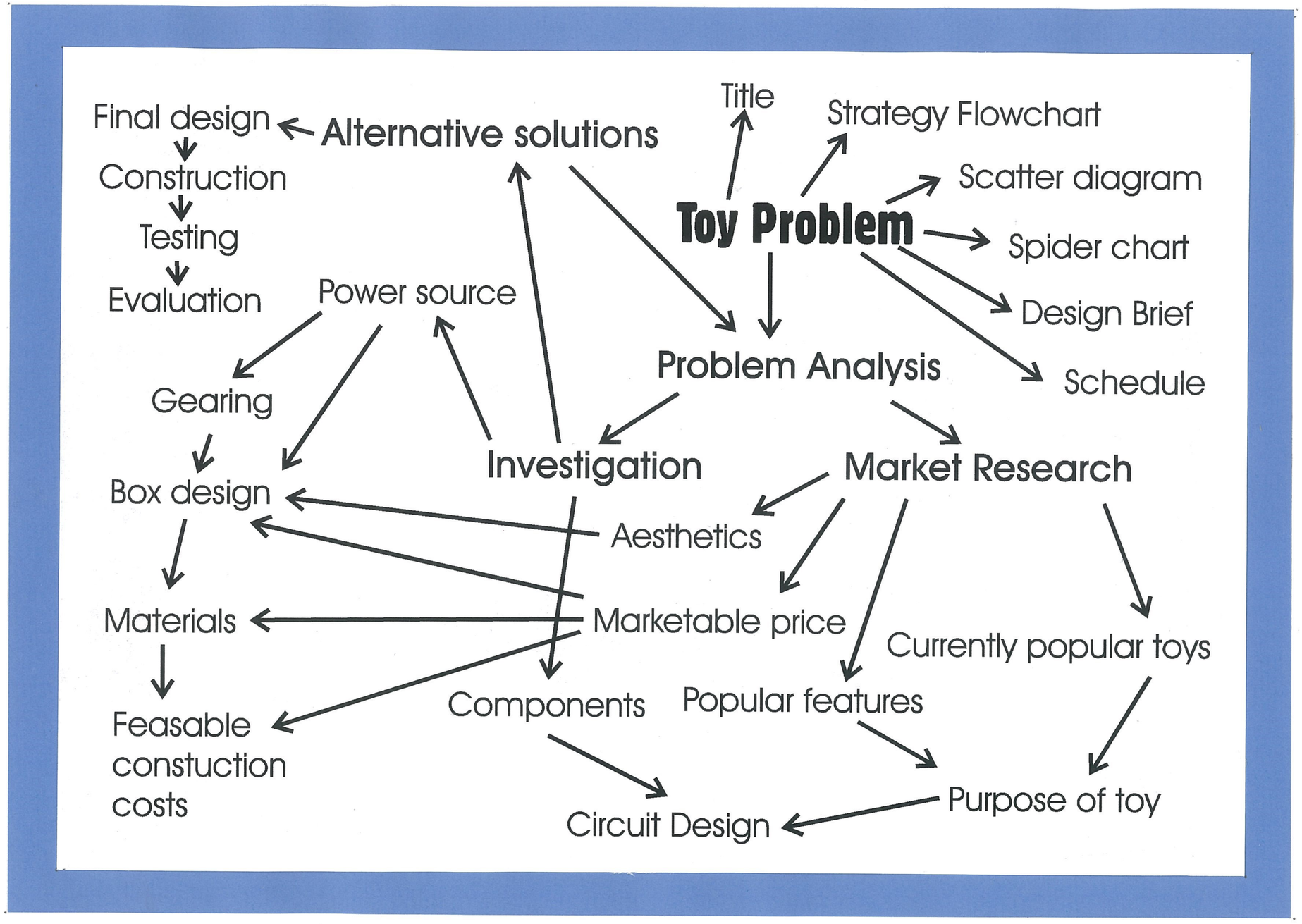
Conception


July
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Conception
Investigation
Analysis
Specifications
Alternative solutions
Selection
Development
Final Design - P.C.B.
Final Design - Box
Production
Modification
Testing
Evaluation
Predicted time
Actual time

Conception


TOYS
0 - 5
WOODEN PLAY TOYS
E.G. COLOURED BRICKS,
CARVED ANIMALS
PLASTIC PLAY TOYS
E.G. BALLS, RATTLES
WIND-UP TOYS
BATH TOYS
6 - 10
CONSTRUCTION KITS
E.G. LEGO
JIG SAWS
"JOINTED" TOYS
E.G. ACTION FIGURES,
ROBOTS, DOLLS
BALL GAMES
BOARD GAMES
PHYSICAL OUTDOOD TOYS
E.G. STILTS, POGO STICK
REMOTE / RADIO
CONTROLLED CARS
L.C.D. GAMES
EXECUTIVE
TABLE - TOP AMUSEMENTS
E.G. NEWTON'S CRADLE
PUZZLES
MASCOTS / MODELS
11 - 16
COMPUTER GAMES
HI - FI
SPORTS EQUIPMENT
MUSICAL INSTRUMENTS

Conception


Final design
Construction
Testing
Evaluation
Alternative solutions
Title
Strategy Flowchart
Scatter diagram
Toy Problem
Spider chart
Design Brief
Schedule
Power source
Gearing
Box design
Problem Analysis
Investigation
Market Research
Aesthetics
Materials
Marketable price
Currently popular toys
Feasable
constuction
costs
Components
Popular features
Purpose of toy
Circuit Design

Conception

Stage 1: Brief

Recognition of problem
Identification of needs
Recognition of situation
Formation of design brief

Stage 2: Investigation

Research into topic
Collation of useful information
Analysis of topic
Specification of requirements

Stage 3: Ideas

Generation of realistic ideas
to satisfy design brief

Stage 4: Evaluating

Evaluation of ideas against
specification
Identification of proposed solution

Stage 5: Developing

Modelling, developing and
refining proposed solution

Stage 6: Planning

Draughting drawing
Planning and organising proposed
realisation

Stage 7: Realisation

Realisation of the solution in form
of model, prototype and final
artefact or system

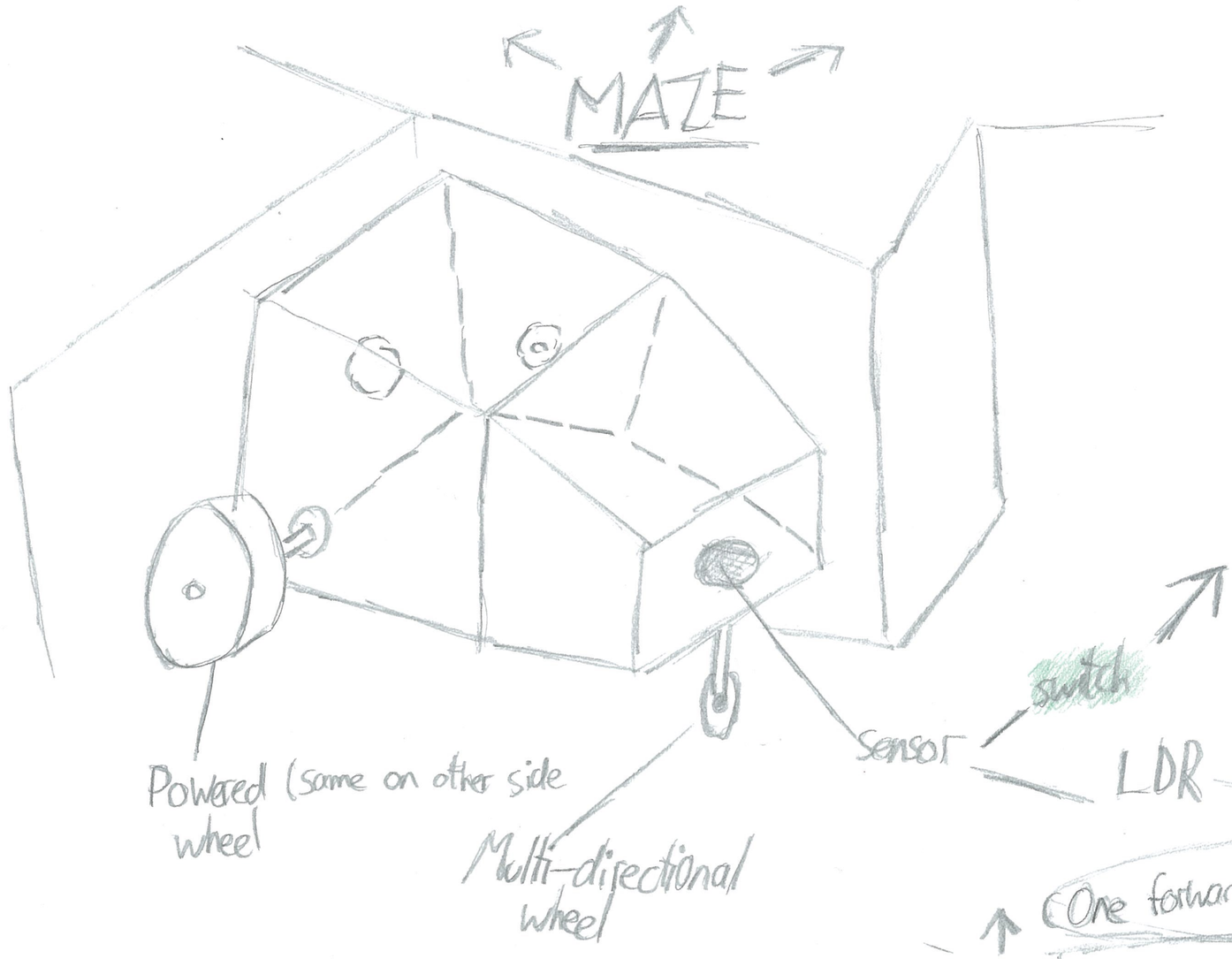
Stage 8: Testing

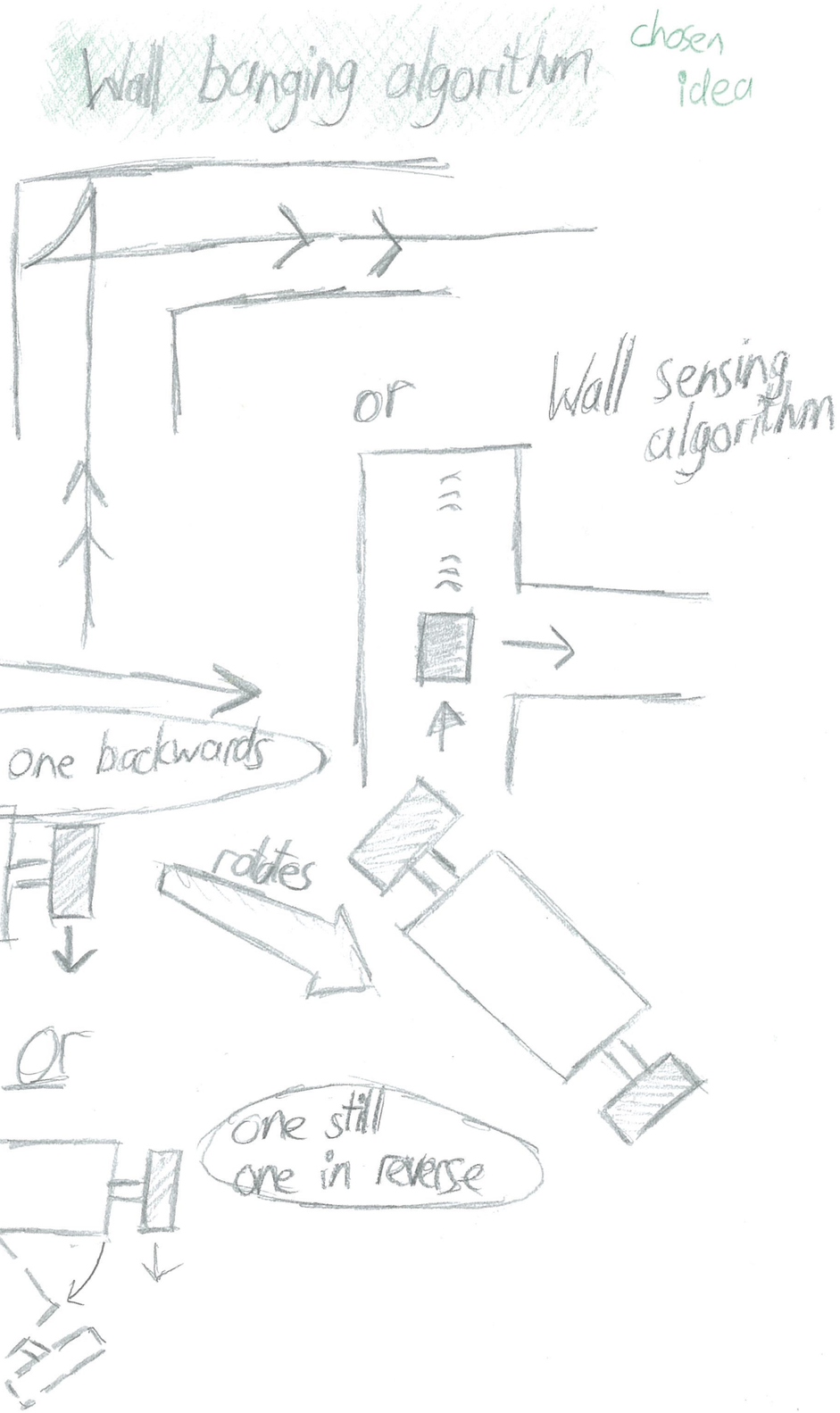
Testing to see if it works and how
it works relative to specification
Possible modification

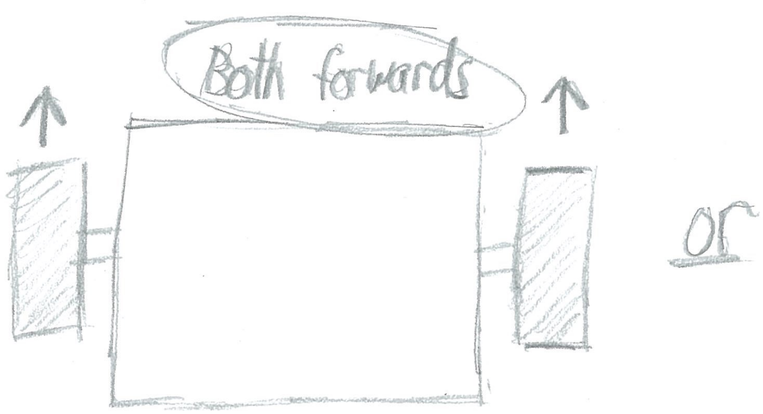
Stage 9: Evaluation

How does it meet brief?
How can it be improved?
How did I tackle the problem?

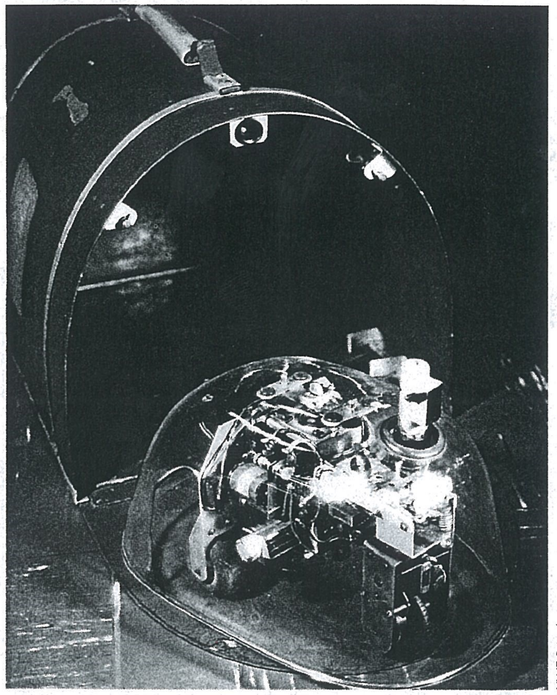
Conception







INITIAL IDEAS



UWE Bristol

Pioneering robot comes to light

ONE of the world's oldest intelligent robots is back in working order. The tortoise—named after the creature who "taught us" in *Alice in Wonderland*—was one of six built by the neurophysiologist Grey Walter in 1950. It has a single light-sensitive eye, and explores a room searching for light. The tortoise also has a touch-sensitive shell. If it gets stuck, it wriggles to break free.

Walter built the robot to help study brain function. It was rediscovered by Owen Holland of the Intelligent Autonomous System Laboratory at the University of the West of England in Bristol, which is next door to the Burden Neurological Institute where Walter worked. "I was absolutely elated when I found it," he says.

The tortoise comes complete with its original hutch. When the light inside is switched on, the tortoise enters and switches itself off as it depresses a switch on the floor of the hutch.

Exert from "New Scientist" magasine.

This robot helped to form the basis for my initial ideas.

Investigation and Research

Market Research

Before deciding on the exact nature of my toy I must survey as wide as a spectrum as possible to ensure there is a market for it, and, should I decide to sell my product commercially, I could recoup my construction costs. More importantly, I must ask my niece for whom the toy is primarily intended for her particular preferences.

Survey Results

Q1 Mean age = 15
S.D. = 0.523

Q2 Maze-solving buggy 43%

Terrain crossing tank 22%
Robotic animal 18%
Stimuli affected robot 9%
Learning robot 4%
Remote-controlled car 0%

Q3a Phototropism 26%
(14% +ve, 12% -ve)
Sonotropism 32%
(19% +ve, 13% -ve)
Impact 89%
(2% set, 87% random)
Human interfacing 52%

Q3b Built for power 92%
Built for speed 77%
Obstacle climbing 23%
Gap crossing 17%
Stopping & starting 16%

Q4 Red 20%
Blue 13%
Yellow 7%
Green 5%
Black 22%
Wood 33%

Q5 Mean price = £ 23.12
S.D. = 1.674

Investigation and Research

Questionnaire

Q1 How old are you?

_____ years

Q2 Which of these electronic toys would interest you the most? (please tick one box)

- Remote-controlled car ☐
- Terrain crossing 'tank' ☐
- Robot which responds to environmental stimuli ☐
- Maze-solving buggy ☐
- Robotic animal which can simulate its movement ☐
- Learning robot ☐

Q3 Which of these features would interest you the most?
(in (a) tick as many as you like, in (b) tick one box)

(a) Direction

Affected by	*Positively*	*Negatively*	*Set*	*Random*
Phototrophism	☐	☐	N/A	N/A
Sonotropism	☐	☐	N/A	N/A
Impact	N/A	N/A	☐	☐
Human interfacing	N/A	N/A	☐	☐

(b) Movement

- Built for speed ☐
- Built for power ☐
- Obstacle climbing ☐
- Gap crossing ☐
- Stopping and starting ☐

Q4 Which colour of box would you prefer? (please tick one box)

- Red ☐
- Yellow ☐
- Green ☐
- Blue ☐
- Black ☐
- Natural wood colour ☐

Q5 What price would you be willing to pay for a robotic toy with some of the pre-listed features?

£ _____

Thank you for taking the time to complete this questionnaire. Any additional comments will also be welcome at any time.

Survey Analysis

It is clear that there is a demand for a maze-solving robot, particularly one which changes direction on every impact with a wall. Many people also would like the robot's driving power to be an important consideration, and many would prefer that the robot itself was uncoloured, i.e. a natural wood colour.

However, it must be noted that my questionnaire was only presented to a narrow range of ages, namely those of my year group, which is not necessarily representative of my robot's most lucrative market sector. In any case, my 8 year old niece's views are most important; after being questioned about my proposed realisation, she was delighted with my plans. She wished to add that she would like the robot to be quite large as she as she dislikes fiddly, little toys.

Naturally, I wish to keep production costs as low as possible as it is unlikely that I would ever actually market the product, although it is interesting that most people are willing to pay around twenty pounds for the sorts of robots I have been considering.

Analysis

Specifications and Considerations

Size	My robot must be relatively small, if it is to navigate mazes, although large enough for a small child to handle with ease.
Cost	The robot should basically cost as little as possible, as I am funding the project from my own purse, although I am prepared to buy components or materials whenever I cannot make do with what the school has to offer.
Shape	The robot's shape is essentially part of its appearance, although it is important that its shape is compatible with mazes and is sturdy enough for a small child to play with without breaking.
Function	The robot must be able to solve basic mazes, or simply navigate obstacles it may find in its path.
Safety	Safety is of mandatory importance as small children do not have the same insights into potential dangers that adults have. Normal safety guidelines for toys dictate that it must contain no easily accessible small parts which could be swallowed, it must not contain harmful substances which could be licked, and it must not have the potential to hurt a child through dropping or careless use.
Finish	The finish is again part of the robot's appearance; it must have a plain finish as my questionnaire concluded.
Reliability	The robot must continue to function as stated if handled with due care, and used as the instructions stipulate.
Appearance	The robot must look aesthetically pleasing in such a way as to grab and sustain a small child's attention.

Specifications and Considerations

Environment	The robot is primarily designed to operate in a maze, although it should also work on any flat surface with optional obstacles of a sturdy nature.
Manufacture	Manufacture should be possible in the school electronics laboratory and use of the workshop where necessary. Production should be completed during the period stipulated in the schedule, although its absolute deadline is February 12th when all project work must finish.
Maintenance	The only maintenance necessary should be to replace the robot's power supply. When this is necessary proper provisions should be made so that anyone can do so with the minimum of inconvenience. The power supply must either be readily available, or similar ones must suffice if need be.
Storage	If the robot is of the size already discussed this should not be a problem. However, the side on which it will be stored must be sufficiently sturdy, so that it will not topple, and with sufficient friction, so that it will not slide.
Materials	The materials used must be cheap, sturdy, easily crafted and safe for a small child to handle.
Ergonomics	The robot must be easy to handle, turn on and off, remove the lid to see inside, and should also be pleasant to touch.
Noise	The robot should not make too much noise as this would upset the child playing with it, and disturb their family.

Some of these considerations will be discussed in greater depth elsewhere - this is merely a summary of the robot's fundamental specifications.

Useful components of possible use to my project

Nor Gate

Symbol



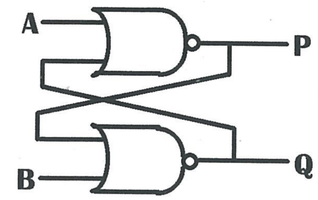
Logic

A	B	Q
0	0	1
0	1	0
1	0	0
1	1	0

There is only an output of 1 if both inputs are 0.

Use in project

Two Nor gates connected as follows are known as a *Flip - flop*



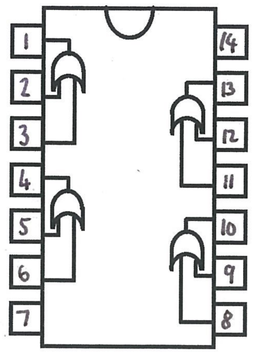
Logic

A	B	P	Q
0	0	1 or 0	0 or 1
0	1	1	0
1	0	0	1
1	1	0	0

By means of a pulse input into A or B, the outputs in P and Q will remain the same even after the pulse is completed. The outputs will then only swap over when a new pulse arrives in the opposite input.

Investigation and Research

Standard Chip: Maplin Quad 2-Input

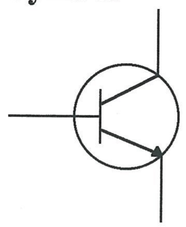


Clearly I can construct a flip - flop from a single Quad 2-Input chip.

N.B. A complete flip - flop chip is also available, but bearing in mind its extra complications such as sets, presets and clock inputs it would not save any time for me.

Transistors - npn

Symbol

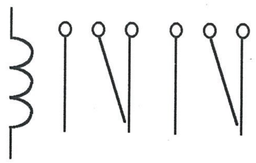


Working

A transistor is an electrically operated switch. It has three legs, collector, base and emitter. When a small current is allowed to flow into the base, current flowing into the collector can then flow onto and out of the emitter.

Relays - double pole double throw

Symbol

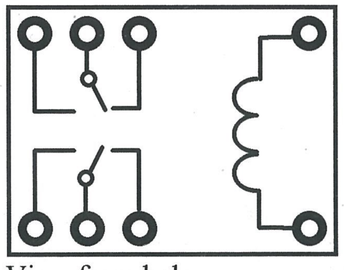


Working

When current is sent through the coil, it becomes energised and attracts the two levers, breaking their circuits with the original connections, and making two new circuits.

When the supply of current through the coil is cut off it quickly becomes de-energised, and the two levers spring back to their original positions.

Standard Component: Maplin 6V Relay



View from below

Motors

Symbol



Working

A current is sent between the motor's two terminals, which, in addition to the the effect of an internal magnet, induces a rotational motion.inside the motor. This motion is transferred to an external spindle. Depending on the polarity of original current to the terminals, the spindle will either rotate clockwise or anticlockwise:

Logic

With the terminals on top and spindle at front,

- + current --> left terminal
  - current --> right terminal

Spindle rotates clockwise

- + current --> right terminal
  - current --> left terminal

Spindle rotates anti - clockwise

Possible types of motor:

Maplin 3V small motor

- Cheap
- Very small
- Low power
- Low torque
- Requires soldering
- Ideal for test purposes

Le Mans Racing Motor

- Expensive
- Very small
- High power
- Low torque
- Requires 7.2V

Como Drills Multi Ratio Gearbox (motor)

- Medium price
- Very large
- Medium power
- Variable torque - up to 4096 : 1
- Will operate at a range of voltages
- Are not laterally symmetrical; mirror image motors unavailable

Power Source - batteries

Symbol



Investigation and Research

Working

Chemicals within the battery induce a potential difference across a positive and negative terminal. If these two terminals are connected by means of a circuit, the chemicals will gradually get electrolysed until the battery is defunct.

Possible types of battery

Ripmax 7.2V Rechargeable Nickel Cadmium Racing Battery * Initial choice

- Requires initial charging before first use
- Charging requires use of a car battery for 5 hrs
- Requires purchase of suitable charger
- Quite heavy and very long
- Outputs through a 'male' connector, so a 'female' connector is necessary before it can bve used
- Voltage is compatible with Le Mans racing motor

GP Greencell 4.5V Battery * Subsequent choice

- Light and compact
- Voltage compatible with Como Drills motor
- Within Maplin 3V small motor operational voltage limits

Power Source - Mains Power

Normal 240V A.C. mains power operates at far too high a voltage for my purposes. Furthermore, alternating current is incompatible with most motors which require d.c. current. However, my school electronics laboratory can convert normal a.c. current into low voltage d.c. current:

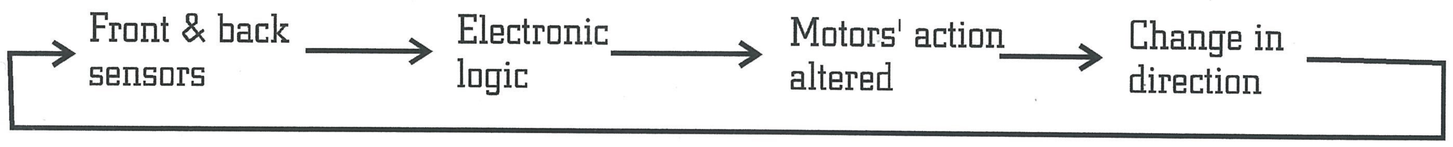
- Mains power is cheaper than battery power
- I do not have to pay for it !
- Leads of finite length are required to connect buggy to power supply
- Buggy's connection to mains is only temporary - easy connection and disconnection
- Buggy is confined to school electronics laboratory and more specifically to bench surface and to vicinity of a power point.

Control Diagram

In order for a robot to solve a maze it will need continuous feedback i.e.



So every collision will activate a sensor and instigate a direction change, which in time will cause a collision with a new wall. Clearly the input represents the front and back sensors, the control represents the electronic logic and the change in direction or on / off state of the motors, and the output represents the robot's new direction.



Clearly this loop should not be potentially infinite because the purpose of the toy is to actually complete the maze. However, knowing quite when this point is reached represents another problem, so it is for the human to judge when the maze is solved and when to turn the robot off.

Development

Path finding

If the robot is to specifically navigate the maze in order to find its 'cheese', then there is scope for a degree of artificial intelligence. This may involve map-keeping, and charting areas of the maze without specifically exploring them. If it is also known that the 'cheese' is in the middle then a sense of direction and location would also be useful.

However, as I believe this complexity to be past my personal limitations I shall only investigate methods involving the following of a precise algorithm resulting from simple sensory information.

Wall banging: This is the traditional 'no-nonsense' method of solving a maze. It involves proceeding in the same direction until a wall is met, at which point a 90° rotation to the right, (or left) is effected and the procedure is repeated..

Pros: This technique can often provide a systematic and comprehensive search of the maze. It only requires simple impact induced sensers.

Cons: It is easily flawed if a section of wall forming a loop is disconnected from the rest of the maze as it can result in the robot going round in circles, or if the necessary turning to solve the maze is mid-way down a passage it will never get the opportunity to go down it.

A similar procedure which involves turning randomly to the left *or* the right after every impact removes most of the scenarios where the robot ends up going round in circles, although it does provide less systematic coverage of the maze.

I see this algorithm as the only practical solution and so I am going to develop it further.

Development of Wall Banging algorithm

Problem 1

Unless the robot is circular, it would be impossible for it to rotate once it has hit a wall. Although I will explore this shape, it will present many constructional problems, so I need to modify the original algorithm in some way:

- Make the robot travel backwards a little way after hitting the wall to give it room to rotate

or

- Assimilate this backwards movement and rotation into a backwards curve

The first option complicates the algorithm by adding an extra step into the algorithm, so I feel that I can confidently discard it. This leaves me with the second option, which has the sole disadvantage of using more manoeuvring space than an on the spot rotation.

Problem 2

I need a mechanism which will ensure that the robot turns by just the right amount to leave it facing 90° to the right or left:

- Use a timing circuit which will leave the robot turning for a set length of time

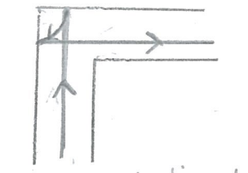
Alternative solutions

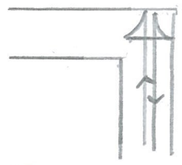
Selection

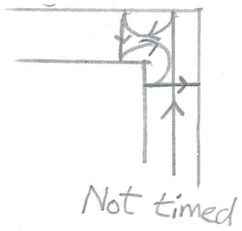
or

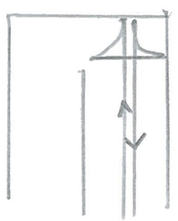
- Leave the robot to turn until it hits another wall 90° from the first wall

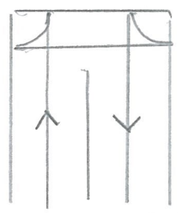
The first option is possible with the well documented 555 timing circuit. However, it leaves the problem of how long the time lag should be, which cannot be decided until the speed of the robot and size of the maze is known; the actual speed of the robot will not be known until production is finished. Still, the size of the capacitors which control this time lag are easy to change.
The second option leaves the size of the turn more to fate; it would require impact with the second wall to trigger a continuation of the algorithm. The second wall may be perpendicular to the first, but this cannot be guaranteed every time, for it would severely limit the nature of the maze. However, larger turns such as 180° or 270° may be no bad thing, for the robot will only tackle the maze in a different way. This leaves me to assess how each solution would tackle the maze:

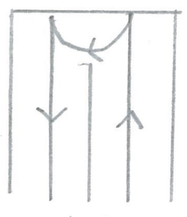












Analysis of the pros and cons of implementing a timing mechanism

From my previous few examples, there are clearly different conclusions to be drawn from each type of turn the robot may encounter:

Straightforward right-hand turn : this evidently presents no problems to either proposal.

Straightforward left-hand turn : neither proposal can cope with a turn of this nature; the timing mechanism causes the robot to return exactly along the path with which it originally bumped the wall, yet without the timing mechanism the robot returns down this path also, but bumping the walls on the left and right as it does so. Perhaps this is advantageous as it may reveal another passage.

Right-hand U-turn : both systems work with this turn.

Left-hand U-turn : a lack of a timing mechanism most excels here, where the robot perfectly follows the turn around. A timing mechanism causes the robot to backtrack as observed with a left-hand turn.

Ideally the robot would continue backwards rather than reverting forwards, if, after reversing through 90°, no impact with a wall had been made. In this way the robot could perform perfect right and left-hand turns. However, to do this the robot would have to reverse through more than 90° to check that there was no wall *at* 90°, and in doing this robot would come out of sync with the maze's perpendicular walls.

Overall I favour no timing mechanism because, although the pros and cons are finely balanced, I think it would be slightly more advantageous not to implement one, especially as this would save on valuable time. Therefore, on collision with a wall the robot will reverse in a leftwards curve until further collision, at which point it will continue forwards again.

Movement

I have already opted for a combination of two types of movement:

Straight forwards
Curving backwards

The former motion can be implemented as follows:

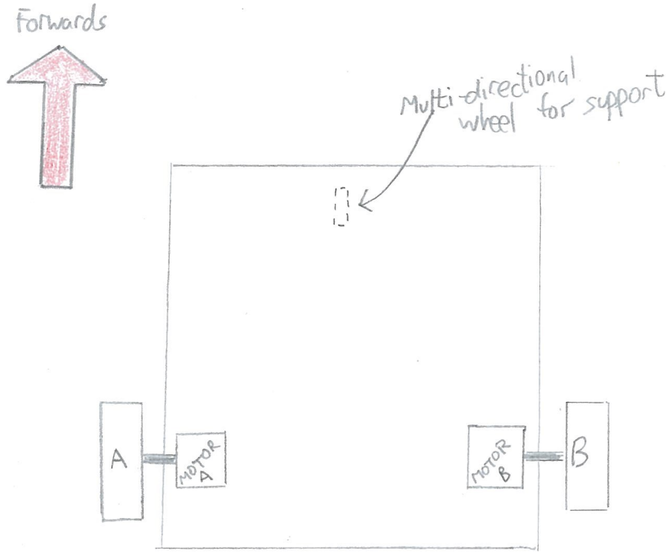
1) One motor on each side, both driving forwards.

2) A single motor on one side driving forwards providing that the wheel on the opposite side can be arranged to free wheel forwards at the same rate.

The latter motion can be implemented as follows::

1) A motor going in reverse on one side as before, and another motor on the other side unoperational while this motion was in effect. This two motor solution is consequently compatible with idea 1 for forward motion.

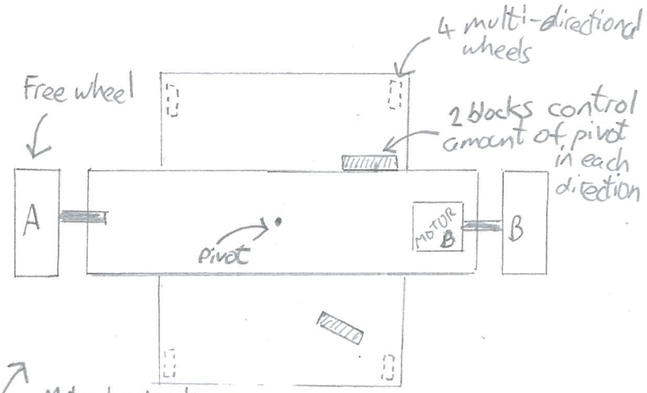
2) A single motor arrangement compatible with idea 2 for forward motion described overleaf...



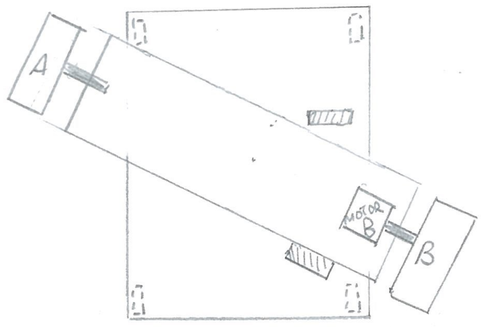
Motors		Wheels		
A	B	A	B	Overall direction
ACW	CW	Forwards	Forwards	Forwards
OFF	ACW	Stationary	Backwards	Curving backwards to left

Implementation of idea 1

Implementation of idea 2



Motor	Wheels		
B	A	B	Overall direction
CW	Forwards	Forwards	Forwards
ACW	Backwards	Backwards	Backwards at chosen angle (probably 90° effecting a left turn)



Alternative solutions

Comparison of possible motion arrangements

Both arrangements intend the robot to 'wall bang'; however:

- Idea 2 can bring about its rotation on the spot, whereas idea 2 brings about rotation in a backwards arc. This means that idea 2 allows the robot to be used in a maze with narrower turnings; however an 'on the spot rotation' may be impaired by the wall into which it has just bumped. (See *Development of Wall Banging Algorithm*.)

- Idea 1 contains two motors, whereas idea 2 contains only 1. This makes idea 1 more powerful, yet more expensive.

- Idea 2 is more of a mechanical problem than an electronic one, whereas idea 1 requires a great deal of electronic logic. Since this project is to be primarily assessed on its electronic content, idea 2 has restricted potential to meet this requirement.

Owing primarily to the last of these points, I will adopt idea 1.

Sensing

The robot can detect walls in a number of ways:

1) By light intensity - the closer the senser is to a wall the sparser the light entering the sensor will be. Hence the robot can change direction before hitting the wall. This is possible with an LDR, whose resistance decreases as the amount of light falling on it increases

2) By sonar - the closer the robot is to a wall the shorter the time a sound wave will take from the transmitter,off the wall, and back to the receiver (a microphone). Hence the robot can change direction left, right, or backwards if in a dead-end, before hitting the wall. (Although this is possible in theory it would be impractical to time how long the signal takes to return bearing in mind the minute distances involved.)

3) By impact detection - when contact is made with the wall the sensor will be activated, leaving the robot no alternative but to reverse away from the wall. This is possible with a push-button switch or microswitch.

4) By prior knowledge - the robot could be pre-programmed with details of the maze. Thus the robot has the potential to turn only when a sensible possibility exists. Providing the maze is constructed as the robot believes it to have been additional sensing devices are clearly rendered unnecessary. (This would be very complicated, so I will not look into it any further.)

5) By learning (in conjunction with methods 1, 2 or 3) - once a particular wall is established the robot can subsequently avoid it. (This would also be very complicated, so I will not pursue this option.)

Alternative solutions

Analysis of sensing devices

Impact-sensitive sensing devices are the only possibility to cater for a wall banging algorithm, therefore I must choose between the many types of push-switches available. I will require two, as my modified algorithm requires sensing at both ends.

Push to make / Push to break

Push to make switches *form* an electrical connection when pressed; push to break switches *break* the electrical connection between their two terminals when pressed. Either when the pressure is relieved or else applied a second time the switches revert to their original state.

This choice exclusively depends on my circuit design.

Locking / Non-locking

Locking switches change state when pushed, although they remain in the same state when the pressure on the button is released, and require a second push for them to revert to their original state (the button pops up after every touch) . Non-locking switches change state when held down, although they revert to their original state when the button is released.

I must choose non-locking switches because the robot requires a pulse signal on impact with a wall; a locking switch would remain pushed while the other sensor was subsequently pushed when the robot hit another wall and the robot would get conflicting signals.

Microswitch / Standard

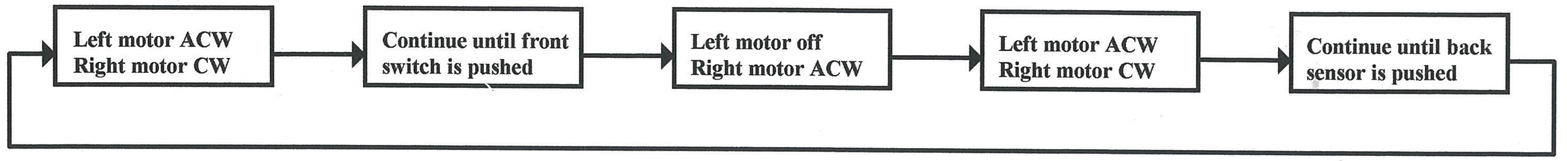
Microswitches require less force to change state than standard industrial switches as they make use of a lever; they are also slightly more expensive. Until production is finished when I will know whether this extra sensitivity is really necessary I shall use standard industrial switches.

Colour & Shape

This is a secondary aesthetic consideration which may well be dictated by whether I choose push to make or push to break switches, and by the switches being push-button, non-locking and a suitable size.

I shall either use Maplin 'Push to Make Low Cost' or 'Push to Break Low Cost' switches, depending on my circuit.

Electronic Logic

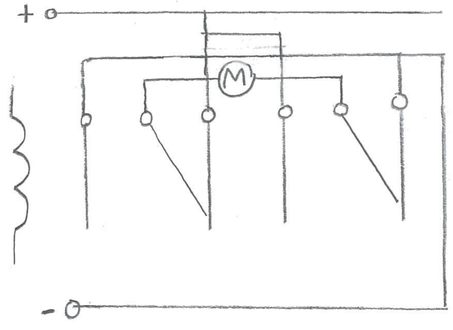


Essentially two actions are happening:

The left motor is being toggled on and off with each impact.
The right motor is being toggled forwards and backwards.

These can be achieved as follows:

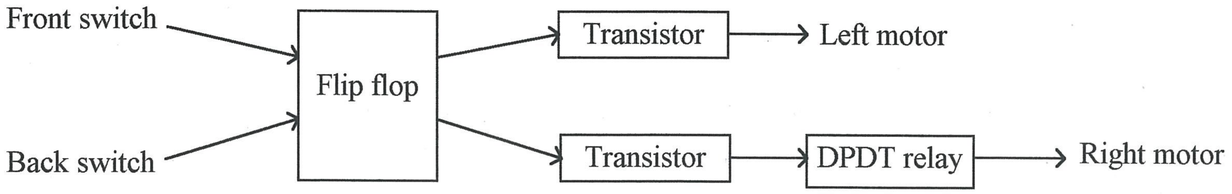
The circuit connecting the left motor can be made and broken with each impact.
The polarity of the right motor can be reversed with each impact by swapping its positive and negative connections around, which can be done by means of a DPDT relay:



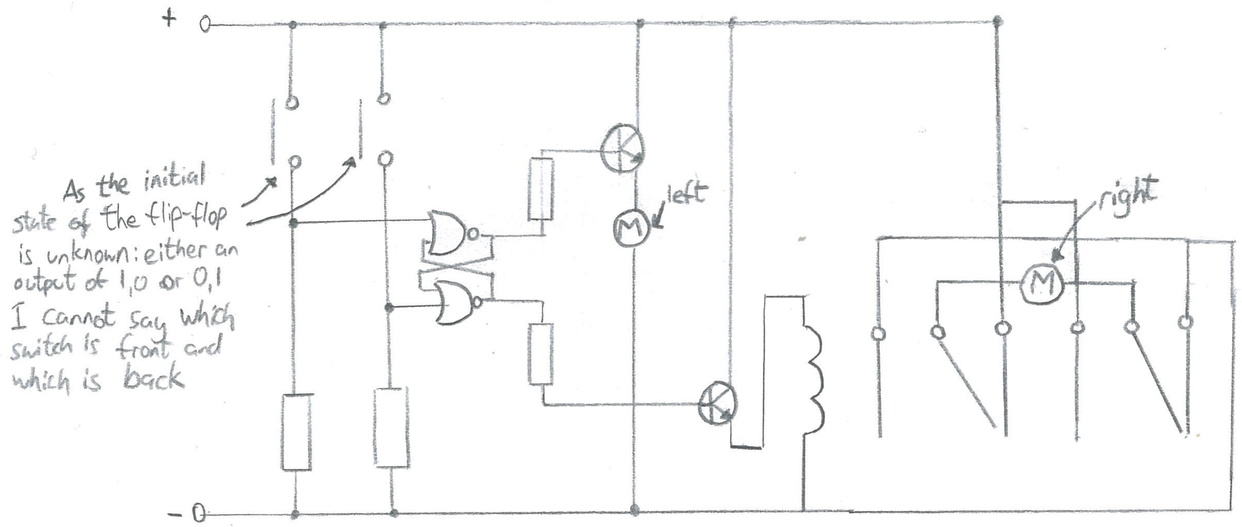
Development

Circuit Diagram A

Both switches can effect this toggling by means of a flip-flop (already researched), which crucially only requires a pulse input. Each pulse can operate a transistor, which would toggle each motor's control circuit, which would both be directly linked to the power supply, with a transistor. The robot will alter its motion when the switch is first pressed, sending a pulse into the flip-flop, and will continue with the new motion even when the switch comes away from the wall and the pulse dies away.



Circuit Diagram:

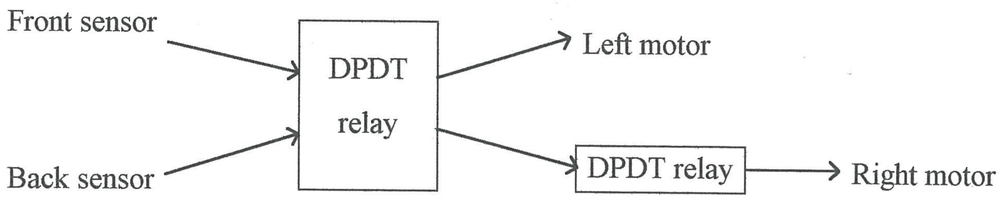


Alternative solutions

Circuit Diagram *B*

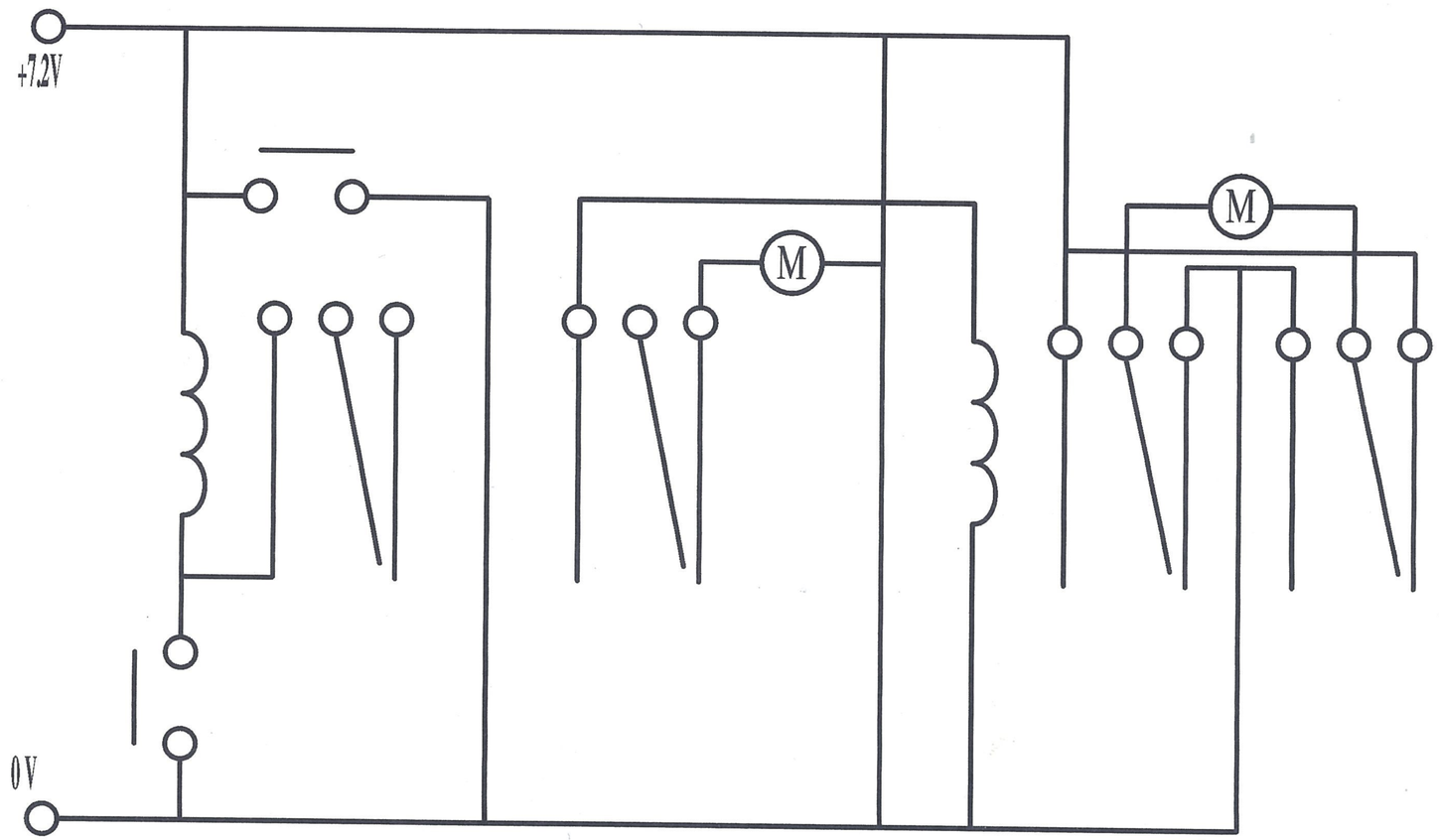
Since the on / off state of the left motor must change in step with the polarity of the right motor, the first change can go on to effect the second. A flip-flop is therefore unnecessary, because the front and back sensory information is now only needed to toggle one motor on and off, which can be done more simply. However, it becomes necessary to sustain the pulse inputs from the switches in some other way. This sustaining can be achieved through an SPDT relay:

When the connector in the SPDT relay swings over to its new connection during the pulse (from the front sensor), this new connection leads back to the transistor coil, thereby self-perpetuating the magnetic. When this electrical link back to the coil is temporarily broken, by means of a push to break switch, or the coil is short-circuited, by means of a push to make switch (as the back sensor), the cycle of self-perpetuation is broken and the connector in the relay returns to its original position.



However, with the DPDT relay, the extra pole creates the interface between the first relay and the second one (controlling the polarity of the right motor), or between the first relay and the left motor, depending on the connector's position. (When in its original position, the left motor is on, and the right is not reversed, when in its new position, the left motor goes off, and the right one becomes reversed in action.)

Alternative solutions



Final Circuit Diagram

Comparison of possible circuits

The logic behind both circuits is essentially identical. However,

- Circuit A contains 11 components: 4 resistors, 1 Quad Nor Gate, 2 transistors, 2 push to make switches and 2 motors whereas Circuit B only contains 6 components: 2 DPDT relays, 2 push to make switches and 2 motors. This means that Circuit A requires more soldering and drilling than Circuit B.

- Circuit B is simpler than Circuit A (in my opinion). Consequently it will be easier to design a PCB for it and the circuit will be easier to analyse if it does not immediately work..

- Circuit A contains an IC, which is generally more temperamental than the relays found in Circuit B, because ICs are susceptible to static and it is more difficult to tell whether or not they are working - one can actually see and hear the parts moving in a relay.

Therefore I will choose Circuit B over Circuit A for the reasons indicated above.

Gearing

Gearing allows one to increase the load of a system, but unfortunately decrease the distance that this load is moved, that is, if the same effort is applied both with and without the gearing. The extent to which the maximum load and distance it is moved can be quantified with the *velocity ratio* and *mechanical advantage*.

Primarily defined, $V.R. = \frac{\text{distance moved by effort}}{\text{distance moved by load}}$ $M.A. = \frac{\text{load}}{\text{effort}}$

V.R. can be transcribed to the context of gearing,

$$V.R. = \frac{D_1 \times D_2 \times D_3 \times \ldots \times D_n \times \ldots}{d_1 \times d_2 \times d_3 \times \ldots \times d_n \times \ldots}$$

where D_n is the number of teeth on driven gear n
where d_n is the number of teeth on driver gear n

Gearing will be necessary in my buggy if the frictional forces posed by the surface it will traverse are greater than the force the wheels can exert, i.e. it cannot move. In which case, gearing will magnify the force the wheels cannot exert, but decrease the speed at which they turn, i.e. the buggy will move more slowly. Gearing can either be implemented as part of a motor, as in the Como Drills multi ratio gearbox, or separate gears, such as the combination available from Mardave (see photographs). This decision depends on ease of mounting and potential velocity ratios.

Development

Materials

Possible materials from which I might choose to build my buggy :

Metal: Metal is very strong, malleable, fairly widely available, heavy and quite expensive. It generally requires mechanised machinery to cut it into shape, and welding to join pieces together, which is difficult to reverse.

Plastic: Plastic is strong though pliable, making it unsuitable if rigidity is required. It is also cheap and widely available. It is most easily used in vacuum forming, by which it can be moulded different shapes. Various plastic containers are also available to buy.

Wood: Wood is generally sturdy, rigid, widely available, of variable weight and reasonably cheap. It requires sawing with either hand held or mechanised tools to shape it. Different pieces of wood can be glued together.

Wood comes in a variety of types; for model making purposes these are most commonly :

Plywood: This is formed as a sandwich of successive sheets of wood of perpendicular grains. Plywood is sturdy, easy to cut, and reasonably light.

Balsa: Balsa is very light and soft, and not very sturdy. It is very easy to cut and to shape, and can be cut with a craft knife if suitably thin.

Principally for its rigidity and ease of construction, I will make the buggy out of plywood (3-ply, 1/8 ″ thickness).

Buggy Design

The buggy design depends on such factors as:

Aesthetics: The buggy must look aesthetically pleasing.

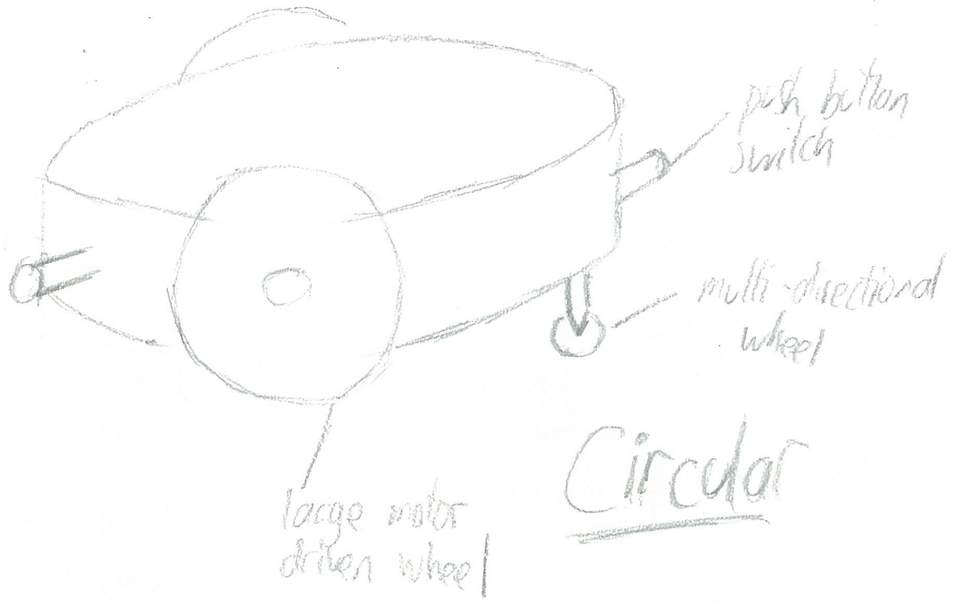
Ergonomics: The buggy must be easy to handle for a young child.

Wall impacts: The centre of the buggy's front and back, where the switches will be situated, must be prominent enough to bump a wall on collision with it.

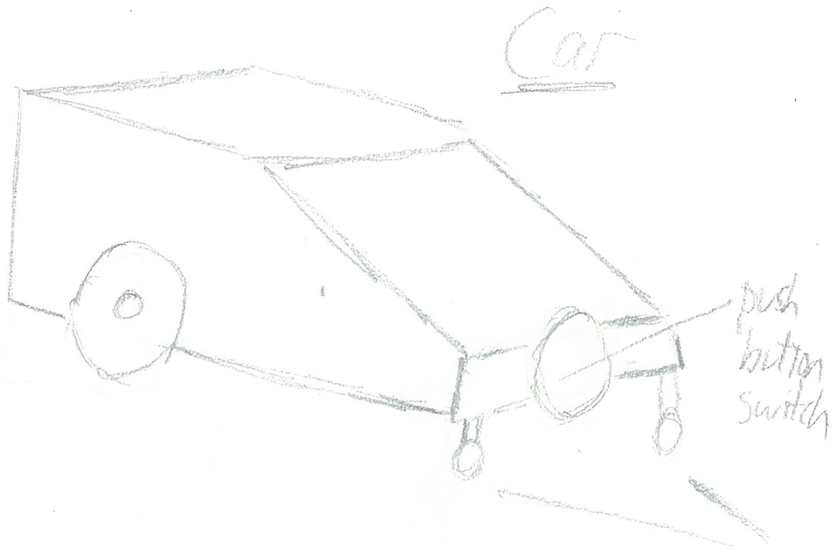
Sturdiness: The buggy's design must be one that can withstand the rigours of being a toy in the hands of a young child. Furthermore, it must also be able to withstand wall collisions.

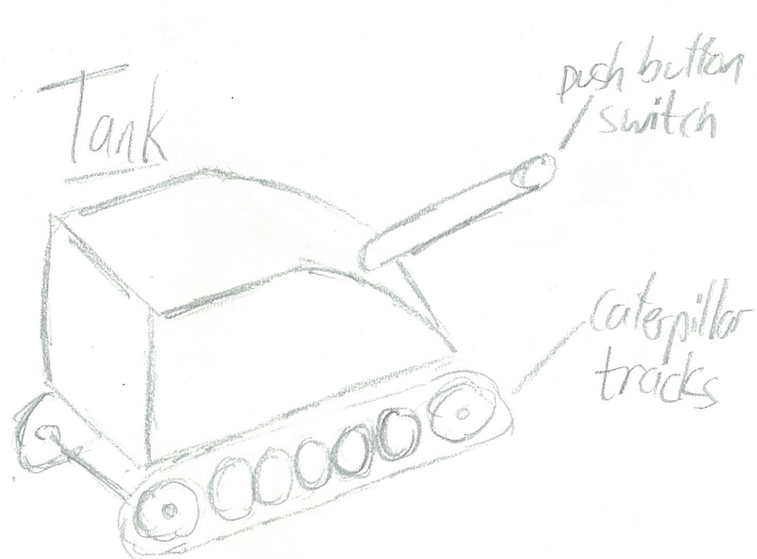
Wheel / Gear / Motor mountings: The design must be compatible with the positioning of wheels, gears, and motors if they protrude through the casing.

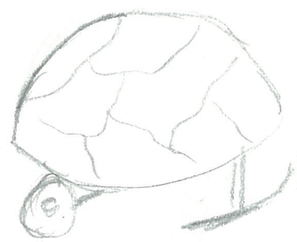
From these criteria, I will devise some possible designs.

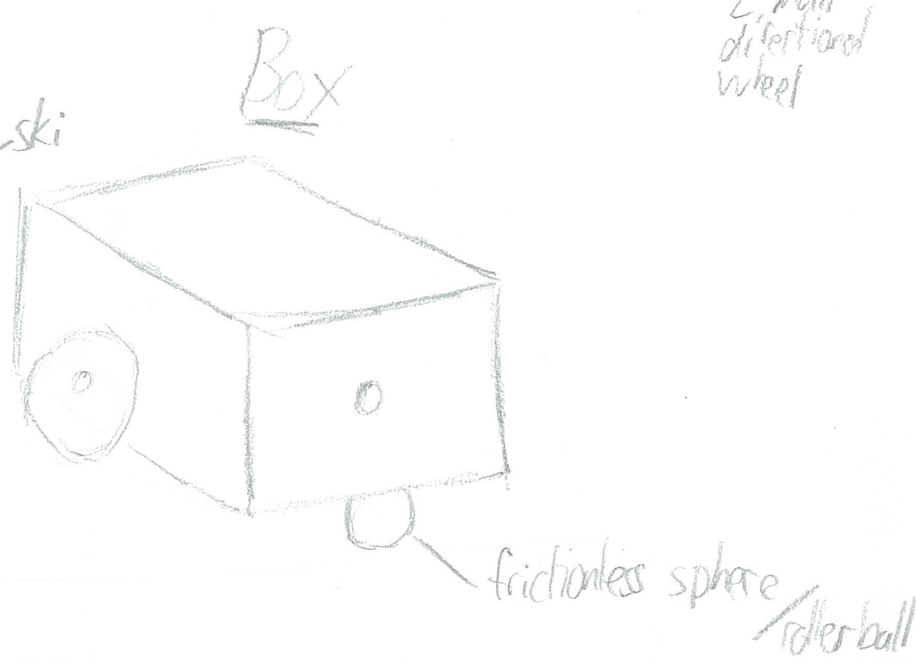


Circular









Alternative solutions

Comparison of different possible buggy designs

The different components of each design such as shape, wheels and sensors will be discussed together even if they are not always mutually dependent. It should be realised that different features of different designs can be combined into a single design.

Circular

This is the best design for navigating a maze in the described manner, because the shape ensures that it is unlikely to rotate into anything other than at the front or back where its sensors would lie. The design is also very intriguing. However, such a design is also difficult to construct and may cause problems in mounting the internal motors against the curved surface. The multi-directional wheels would allow the robot to turn unimpeded and with minimal friction. The large wheels provide a good velocity ratio though low mechanical advantage. They are also aesthetically pleasing in the way they rise the same distance above the top as beneath its base. Unfortunately there does not appear to be a great deal of scope in different size wheels in various designs. Both wheels would have to be either side of the circle's centre, and therefore neither end will appear to be the *front* or *back*. Thus neither 'forwards' nor 'backwards' motion will appear more 'usual', and extensive reversing will therefore not seem out of the ordinary.

Car

This is an interesting design. However, it must be reasonably long if it is to observe the traditional shape and proportions of a car, and this may impede its navigation of a maze - it is not particularly suited to rotation. The large circular sensors pleasingly evoke car bumpers. The wheels are a normal size. Construction is certainly feasible if demanding. The two multi-directional wheels are again a good idea and appropriate for a car even if they are unavailable. The sense of realism is generally well achieved.

Box

Although uninspiring a simple box design is easy to construct and allows me to arrange my electronics and motors in a sensible and ordered fashion within, connect the wheels and motors in any position down the buggy's sides because the sides are completely uniform, and attach the sensors at any position on the front and back, with room to add additional sensors if desired. The large flat front and back surfaces mean that I could stick suitable images on to make the buggy look generally more pleasing and interesting. A roller ball provides less friction than the sphere, although they are evidently unavailable in most model-making catalogues and difficult to construct oneself. A sphere, though easy to find and include, restricts the type of surface the buggy can traverse to smooth ones - it is unlikely that carpet would be feasible.

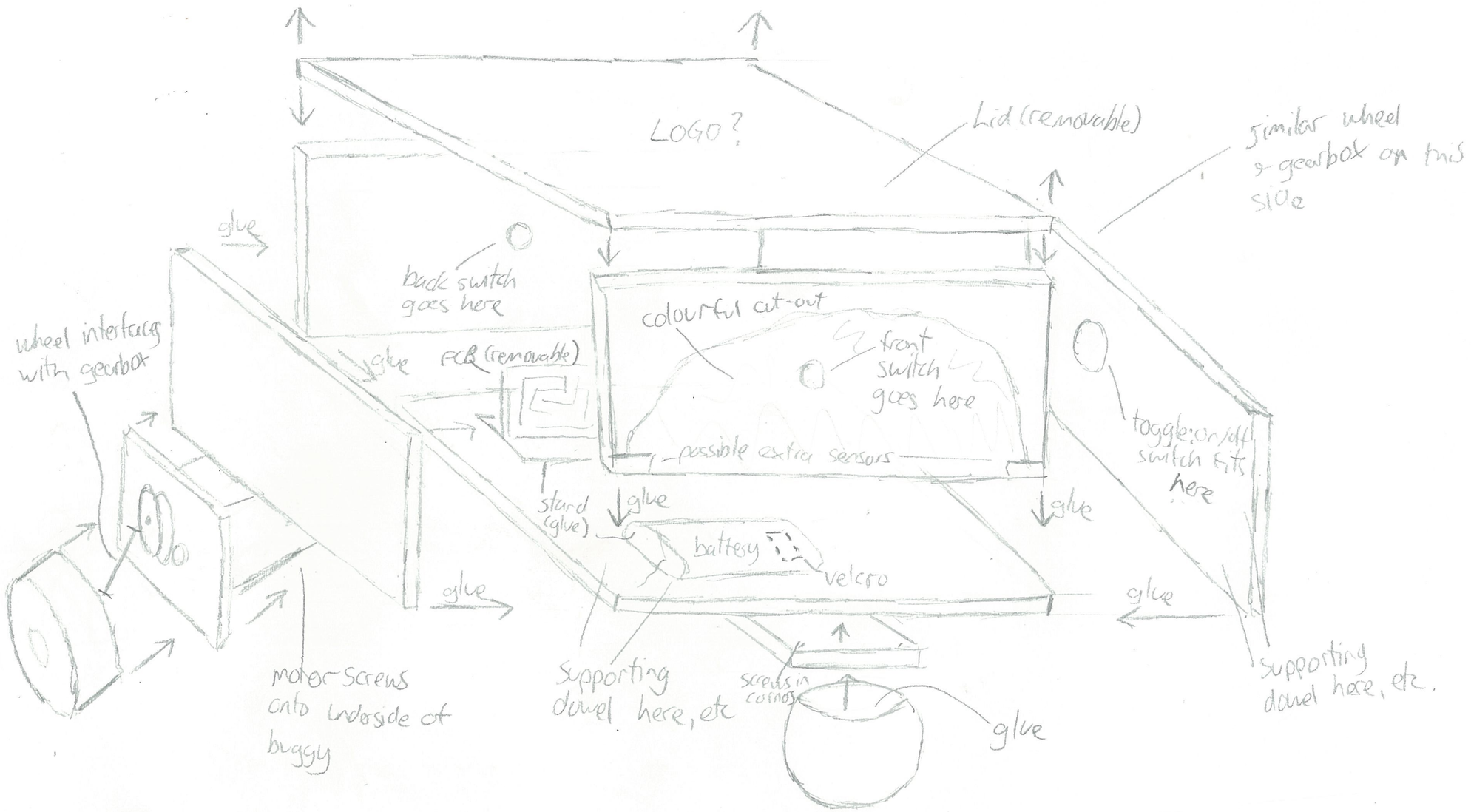
Tank

This is perhaps the most novel design. However, it might prove difficult to construct, especially the caterpillar tracks and the curved front, and the protrusive gun, fragile itself, results in one possible position for the front sensor: on its tip, and this might prove difficult to arrange successfully. Each caterpillar track is likely to require more than one motor, which I have not bargained for.

Tortoise

This is another novel design. The covering shell makes it sturdier to knocks from above, although having the wheel and motor mountings below the casing itself makes it vulnerable from below, particularly if dropped. The shell lends itself to a colourful decoration. The front ski is unlikely to be practical because the edge of the ski would be pushed along the floor - it may as well be the sphere I have described above, albeit less novel.

Overall I favour the box shape because it provides the greatest number of opportunities for mountings - these will be easy to change if my initial ideas do not carry through successfully. I also favour standard size wheels, basically whichever best conforms to the motor connections. However, I cannot yet decide between a single multi-directional wheel and a solid sphere, and whether to mount my motors within or without the case. Thus I will investigate these further.

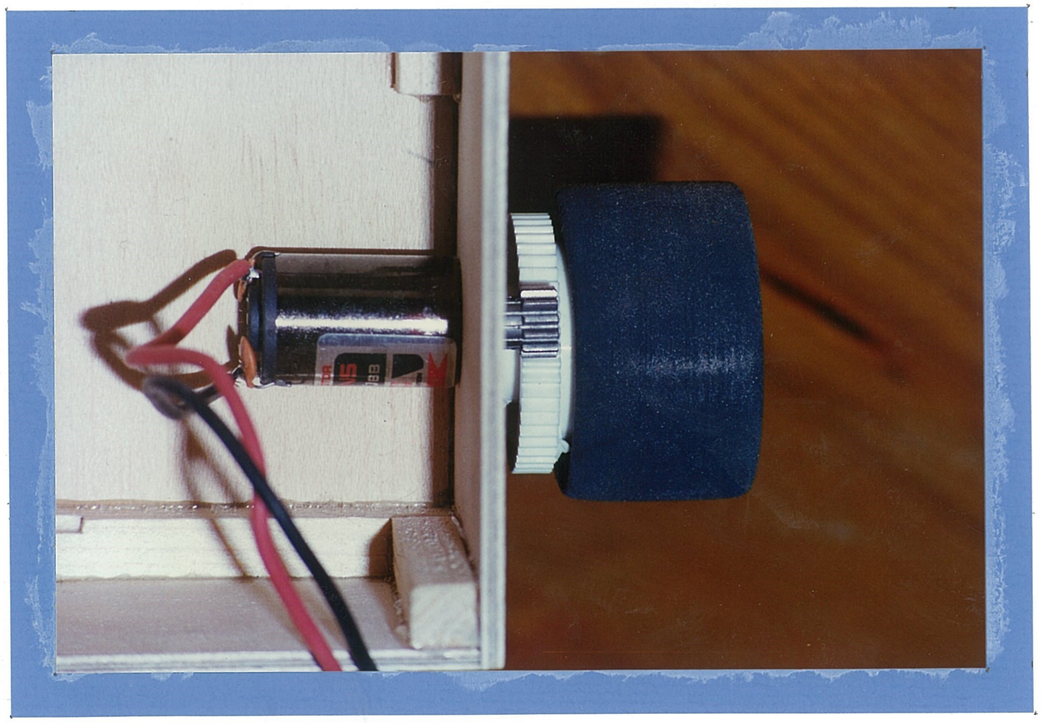


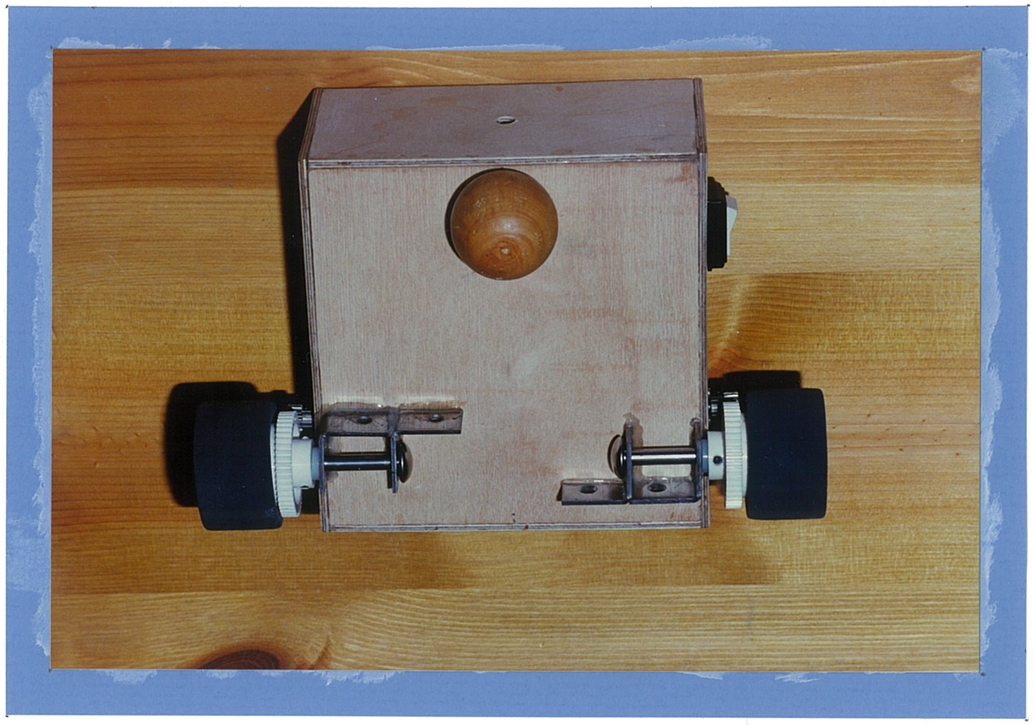
Development

Arrangement of Motors

My initial idea was to mount two racing motors either side of the buggy *within* the casing. I drilled holes on either side of the buggy through which each motor axle could protrude, and two extra holes on each side for screwing each motor into position. I pushed a piece of copper tubing onto each motor axle in order to provide a tight fit with the gear to which it would interface. On the underside of the buggy, I arranged two brackets on either side to support each wheel axle; each wheel had an in-built gear, specifically designed to interface with the smaller gears. The ends of each wheel axle were stoppered with two hemispherical caps, each one with a sprung membrane to grip the axle with. These, together with the two plastic washers positioned next to the wheels, kept the wheels quite secure.

However, on testing this arrangement, simply by connecting each motor directly to the battery, it was evident that the copper tubing which was interfacing the motors with the first gear was slipping when the motors were activated. The problem was evident: the motors were simply not designed to interface with the gearing combination. It was also apparent that the wheels were spinning far too quickly and jerkily to be congenial. Consequently this particular arrangement was discounted as it currently stood.



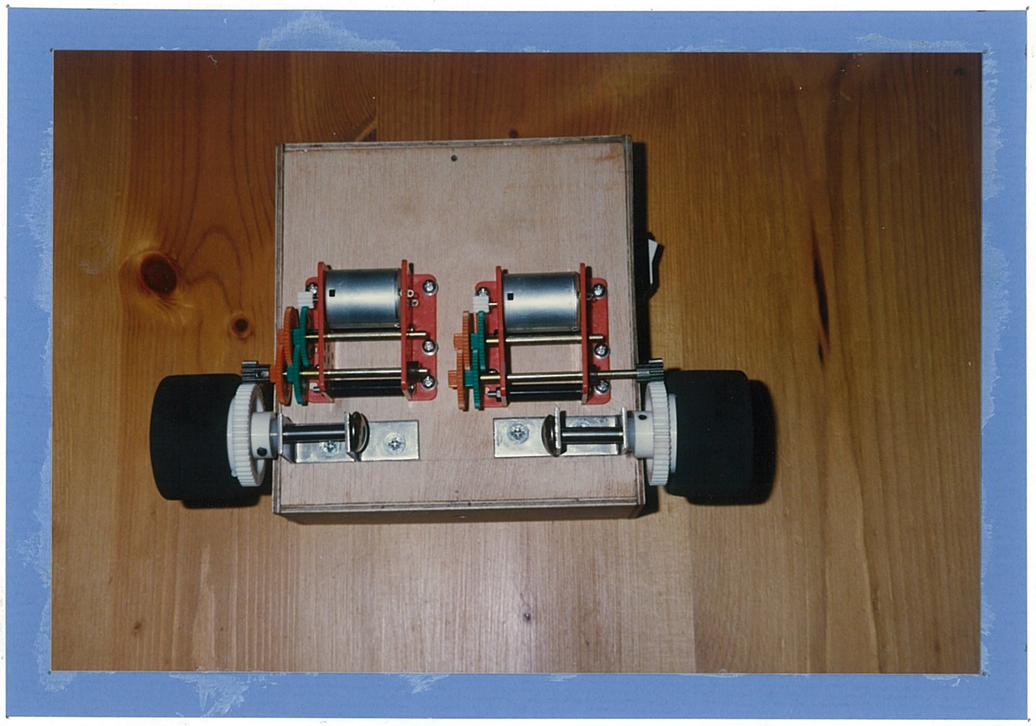


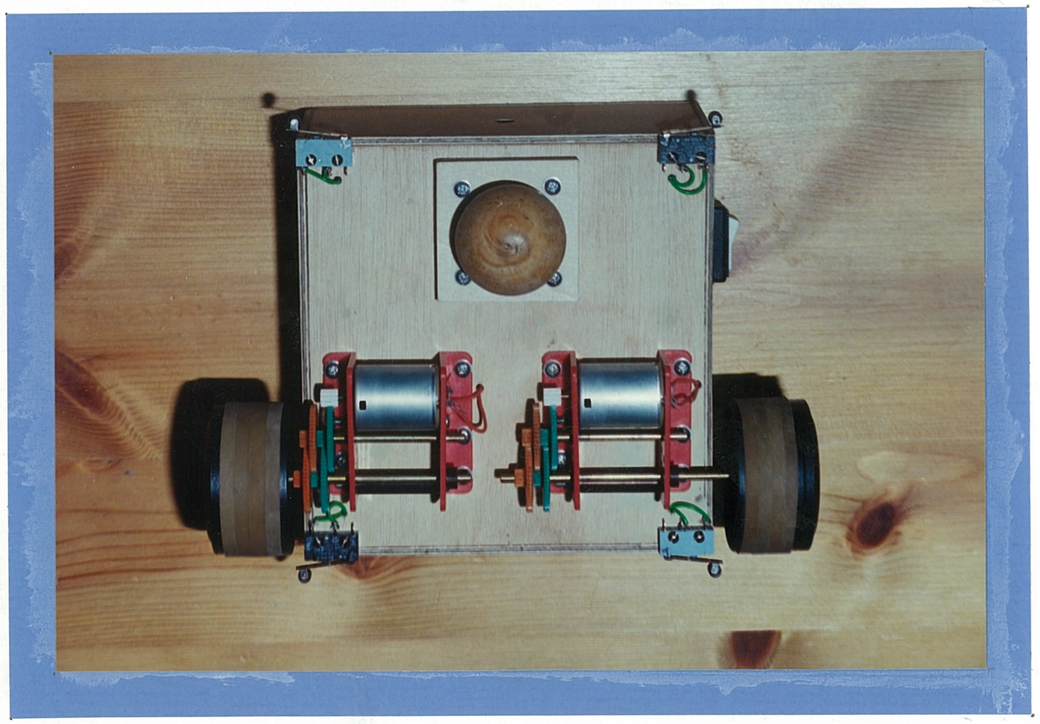
Alternative solutions

Development

My subsequent plan was replace the racing motors with two MFA Como Drills Miniature Gearboxes (gearbox and motor combined into one unit) principally because the output shaft was exactly the same diameter as the smaller gear from the last arrangement. However, if the unit was positioned *inside* the buggy casing, as before, the small gear would not have made sufficient contact with the wheel gear to drive it properly. Thus the only option was to mount both units on the *underside* of the buggy - in this way the small gear could be positioned comfortably half way up the wheel gear, meshing nicely with it. (As the wheel axle was below the buggy's base, a greater proportion of the wheel itself protruded below the base than above it.)

After connecting both motors in series with the battery, it was clear that the buggy was moving much more smoothly than before, and its speed was definitely more reasonable. However, the buggy was making a very loud noise, and I realised that it would be far more sensible to amalgamate the gearbox with the external gears in order to cut out an unnecessary interface. This led to my final arrangement.





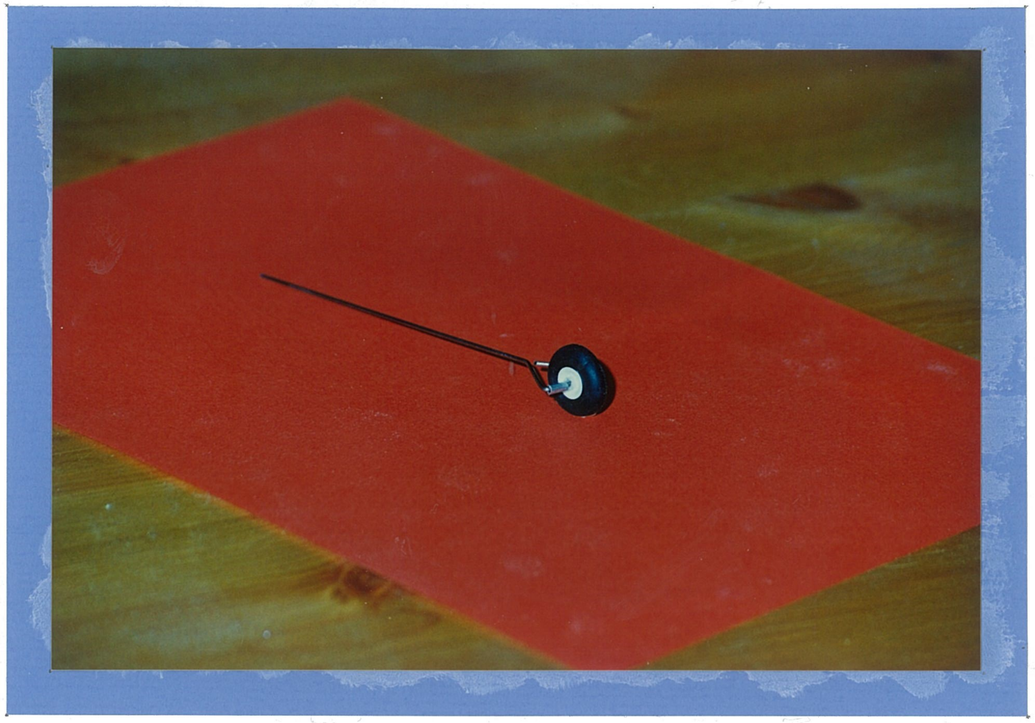
My final arrangement saw the abolition of the external gears, wheels and support brackets from the previous arrangement, and I simply slid my new pair of *ungeared* wheels directly on to the gearbox's output shafts. These wheels were specifically designed for such a use. To compensate for the increase in velocity ratio resulting from the loss of gears external to the gearboxes, I simply inserted another pair of gears into each gearbox - these were specifically multi-ratio gearboxes, and I had already removed two pairs of gears for the previous arrangement. However, the new wheels lacked a decent tread, notably a superlative feature of the previous ones. However, this disadvantage was only a minor one; it was remedied through the addition of four tightly fitting rubber bands around each wheel. Albeit crude, these seemed to serve their purpose nonetheless.

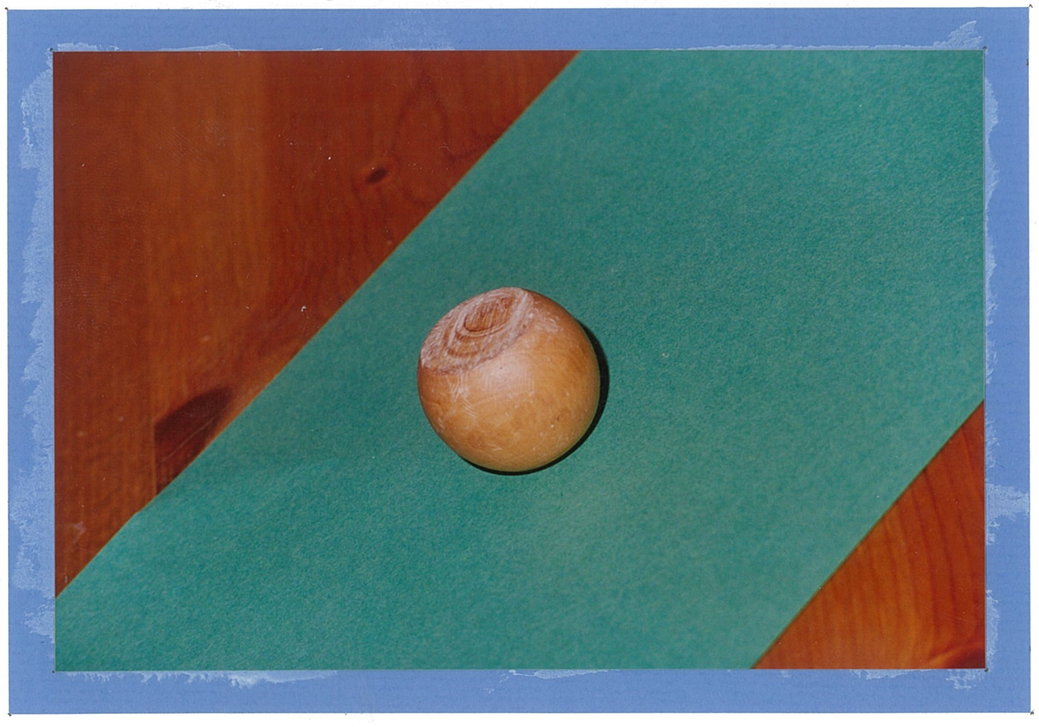
The buggy performed smoothly and cleanly - at a congenial speed. It was still fairly loud, however. (See Modifications.)

Possible Front Supports

My first construction was a multi-directional wheel. To build this I bent a length of coat-hanger wire through 110°, slid on a short length of copper tubing up to the bend, followed by a small model-making wheel and another short length of copper tubing, and finally bent the wire once again through another 110° where the latter piece of tubing stopped to form a closed isosceles triangle. The two pieces of tubing were to keep the wheel fixed in position. I cut the unwanted coat-hanger wire at the triangle's upper vertex. I then slid another length of copper tubing onto the remainder of the wire. Next, I drilled a small hole at the front of the buggy wide enough for the coat-hanger wire to pass through - this I duly did. The buggy was now able to stand securely on the floor - the front of the buggy rested on the copper tubing.

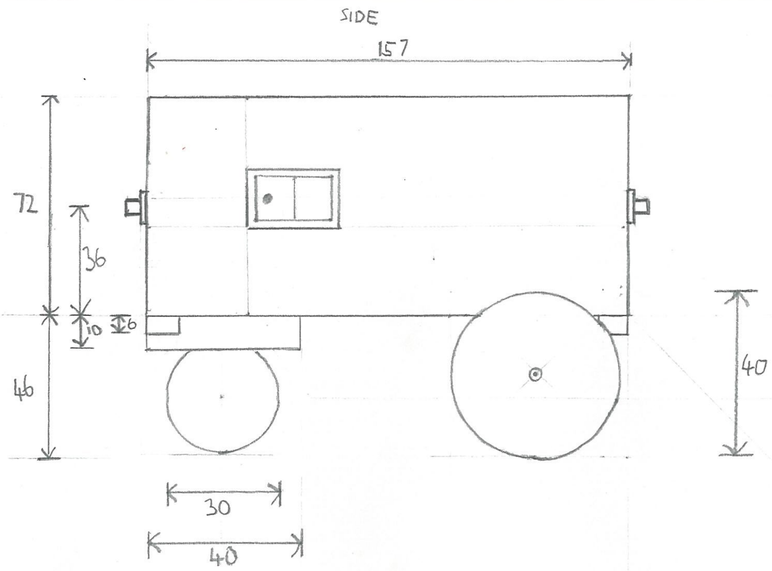
However, on testing this support it was quickly evident that the wheel was not stable enough: it wobbled while the buggy moved forwards, and failed to change its direction as the buggy reversed clockwise. Much of the time it did not even appear to be turning. Hence I tried a different solution.

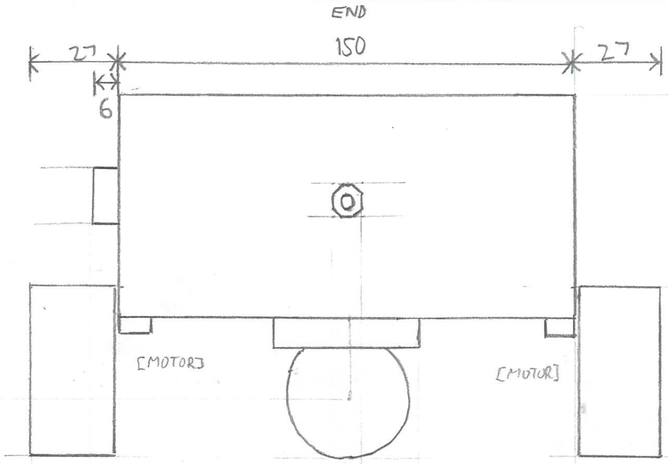


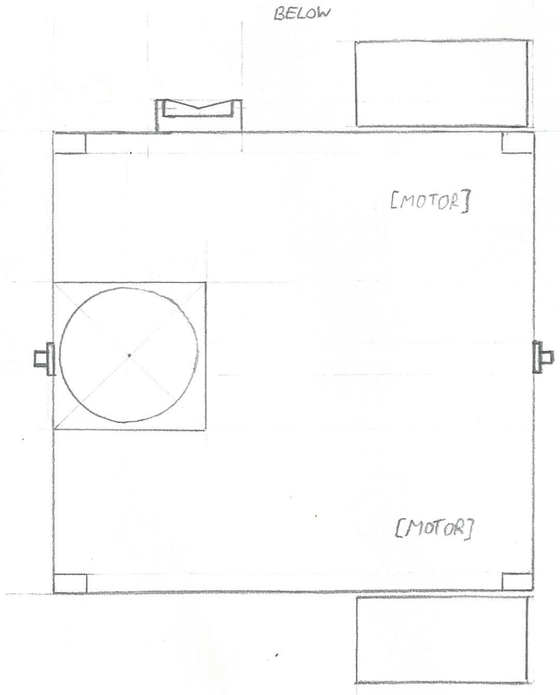


Next, I tried building the spherical support, also previously proposed. I found a suitably sized wooden one in an unwanted bowls set. However, it did not seem that the sphere's upper surface, by its very nature, was broad enough to attach directly to the base of the buggy, and so I decided to cut away a small segment from the top of the sphere. With this broader base it was now suitable for mounting, although an additional interfacing block (a three slice sandwich of plywood) was needed to make up the height difference with the back of the buggy. I glued the truncated sphere onto the block, and this I screwed onto the underside of the buggy. Finally, I made small adjustments to the amount each screw was protruding into the wood in order to fine tune the base of the buggy to become parallel with the floor.

On testing this new support, it was immediately apparent that it provided ample support and posed only minimal friction to the moving buggy. Thus I adopted this support as a permanent feature of the buggy.







ALL MEASUREMENTS ARE FINISHED IN MM
APPROX SCALE 1:2

Final design - Box

Cutting List

All dimensions in mm
Finished sizes given

Description	No Off	Length	Width	Thickness	Material
Side	2	157	72	3 (1/8 in)	3-ply plywood
End	2	143	72	3 (1/8 in)	3-ply plywood
Base	1	150	143	3 (1/8 in)	3-ply plywood
Lid *	1	157	150	3 (1/8 in)	3-ply plywood
Reinforcing dowel: **					
lengthways	4	130	10	10	deal
widthways	4	123	10	10	deal
vertical	4	65	10	10	deal
Front supporting sphere	1	/	/	/	beech?
Interfacing block (3 component sheets)	3	40	40	3 (1/8 in)	3-ply plywood

* Rather than just using these measurements straight off, construct and glue the base, sides and ends first, and then make a lid whose shape is compatible with the actual upper rim, which may well be slightly warped and not contain exact right angles.

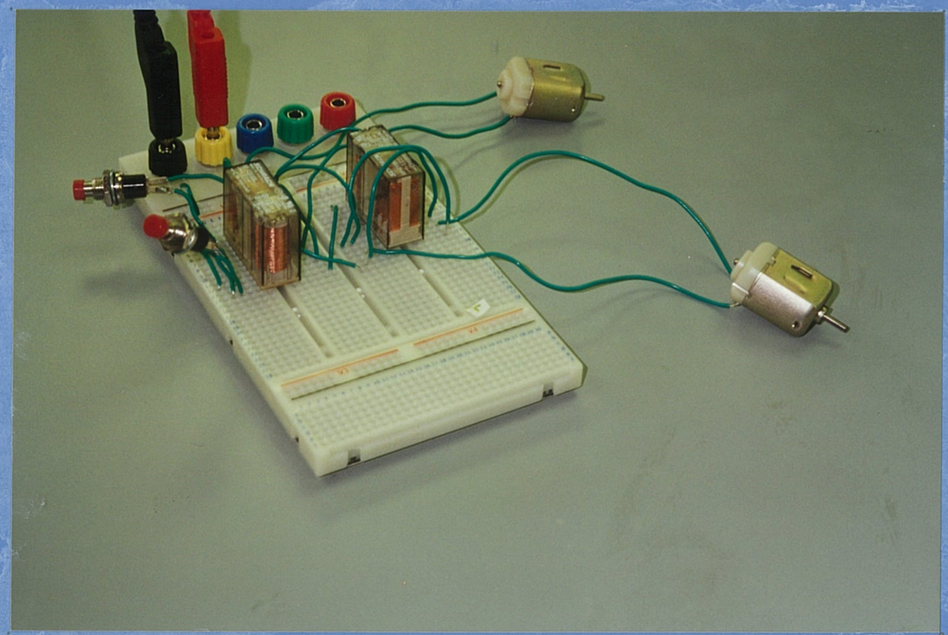
** Rather than just using these measurements straight off, mark the length of the piece of wood to which it will adjoin on a length of dowel, and then subtract the relevant number of actual thicknesses of plywood or dowel. This will procure measurements which are significantly more exact.

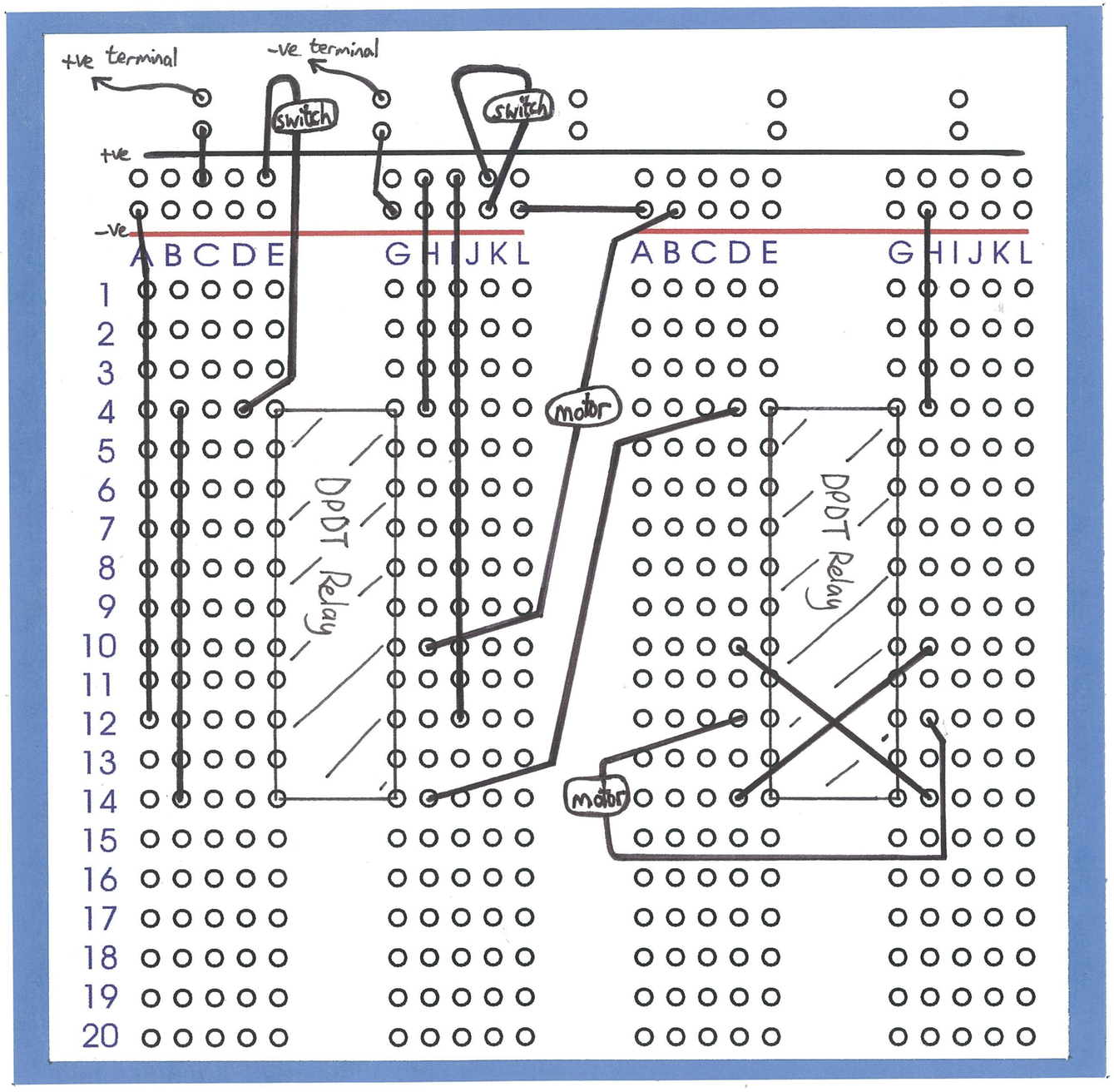
Production

Development of a final PCB design

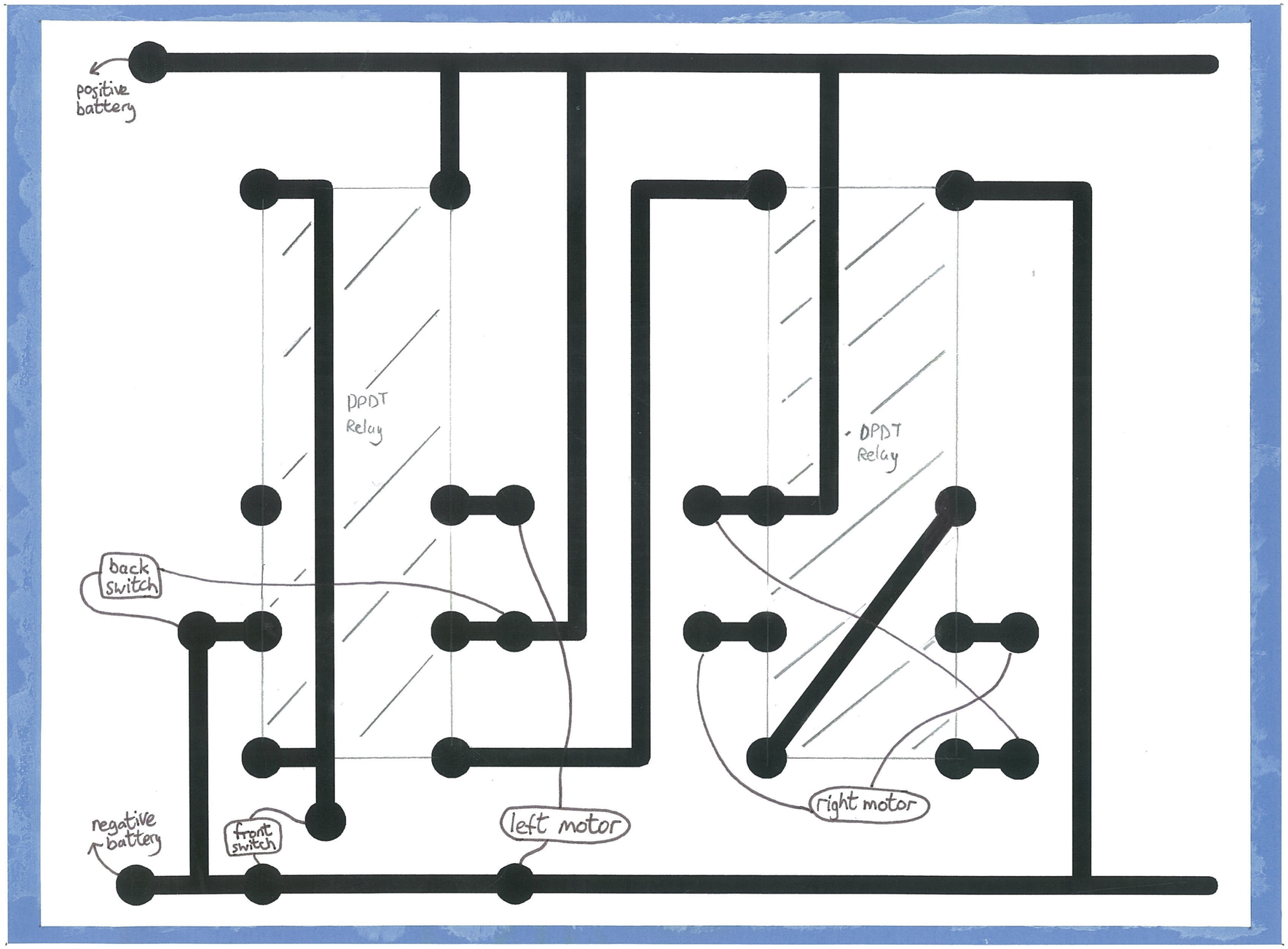
Once I had established my circuit diagram, the next stage was to implement it onto breadboard: each relay was positioned across a vertical break, left and right of the breadboard. Wires and relay connections which all originated or terminated at the same 'node' on the circuit diagram were inserted onto the same row on the breadboard (each row of five holes are electrically equivalent). Positive and negative rails were assigned at the extra rows at the top of the breadboard; each of these rows was then connected to one of the input and output leads, which were duly connected up to the power pack. Switches and motors also had to be soldered up to connecting wires - for the time being I used Maplin Small Motors, perfectly adequate for testing purposes if not powerful enough to drive a buggy. After turning on the power supply my circuit worked according to specification: the motors changed direction and went on and off as desired, and the mechanical action of the relays could be seen and heard working properly within their casing.

After taking note of my breadboard layout, I began the process of designing my PCB. This essentially involved converting the connecting wires on the breadboard into tracks on a circuit board. However, where wires on the breadboard could cross over each other, tracks on the PCB design specifically could not cross as this would have electrically joined the two tracks. If cross-over tracks did seem unavoidable, jump wires were used, although these had to be kept to a minimum. Nodes for relay legs and connecting wire for switches and motors were marked by a circle. (The nodes for the relay legs were 0.2", 0.2", 0.6" apart on each side.) Some tracks could even be taken beneath the relays, though obviously nodes could not be placed along these particular tracks as there would not be room for making connections. The whole circuit design was compacted into as small a space as could accommodate the size of the relays.





Development



Final design - P.C.B.

Production Plan

Mechanical section:

Tools	Process	Comments
Band saw	Ends, side and base cut out	Cut on outside of guide lines
Hack saw	Reinforcing dowel strips cut out	
Glass paper	Surfaces smoothed on all pieces of cut wood Shorten wood to exact chosen measurements	Rub evenly along whole surface
"Pritt stick"	Tank cut outs glued to ends	
Hole saw	Hole cut for on / off toggle switch on one side	Cut slightly too small to provide a tight fit for switch
Drill	Hole drilled in each end for push button switches Holes drilled in base for connecting wires	
Epoxy resin glue	Each reinforcing dowel glued to one piece to which it will adjoin Four sides glued to base	Cross hatch surfaces to avoid ambiguity

Band saw	Lid cut out	Trace around outer contour of four sides to procure exact size for lid
Epoxy resin glue	Four strips of dowel glued to lid	
(Nothing)	Both gears on *one* motor transferred onto opposite side of axle	
Screwdriver	Both motors screwed into place on underside of base	
(Nothing)	Wheels pushed onto axles Four rubber bands placed around each wheel for extra grip	
Band saw	Wooden square from front support sphere cut out End of wooden bowling boil cut off	
Epoxy resin glue	Truncated sphere glued onto middle of wooden square	
Drill	Holes drilled at corners of wooden square	
Screwdriver	Wooden square screwed onto underside of buggy as front support	

Production

Electronic section

Computer	P. C. B. layout designed	Remember to mirror image design
Printer	P. C. B. layout printed out on tracing paper	
Craft knife	Circuit cut to suitable size for a UV light-box	
UV light-box	UV light is shone through tracing paper onto P. C. B. for 3 minutes	Ensure tracing paper is positioned with correct side uppermost
Sodium Hydroxide	P. C. B. design developed in chemical bath	Continually jiggle P. C. B. to prevent bits settling over the tracks
Iron wool	Vigorously rub circuit board tracks to make them shiny	
Drill	Drill holes for the relay legs and connecting wire	
Soldering iron	Solder the relays, connecting wire, and battery holder into the P. C. B. Solder connecting wire to all switches and motors	Screw toggle switch into hole from outside before soldering
(Nothing)	Switches pushed through holes in ends and metal rings screwed on from opposing side. Batteries inserted into battery holder	
Hack saw & Strip heater	Stand made for circuit board to stand upright	
Epoxy resin glue	Stand glued onto buggy's base	

Production

Modifications

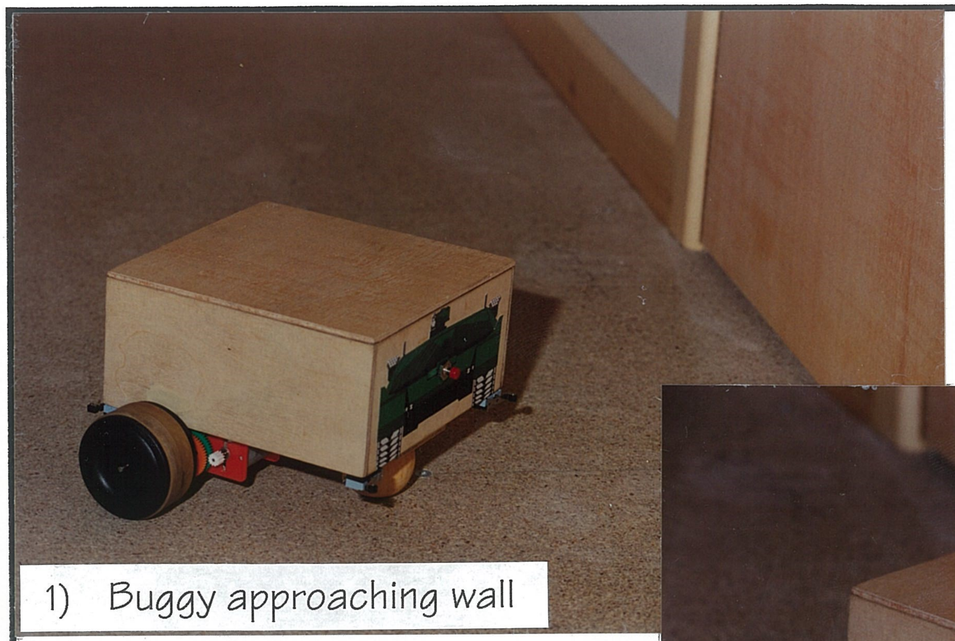
It soon became apparent that the tracks on my PCB kept getting burnt out when the power supply was connected; each time this happened I had to repair the break by soldering on lengths of stripped copper wire. The only possible reason for this seemed to be that my enormous 7.2V racing battery was supplying too much power along the tracks. Thus I replaced this battery with a smaller 4.5V battery. As I thought would be the case, the tracks stopped burning out.

After a few simples tests with the buggy, simply pushing the push switches by hand, I discovered that the secondary relay was rather unpredictable - the switching arm oscillated between switching functionally and consistently and only switching half way between the contacts (this could be seen through the plastic casing). In the latter case it was necessary to jiggle the push switch repeatedly, and eventually the switching arm would switch all the way across. In terms of movement, when the back switch was pressed, the stationary motor restarted itself as it should (this motion is wholly controlled by the primary relay), but the backwards motor failed to revert to forwards motion, at least, for a large portion of the time. (The front switch always operated perfectly well, always implementing the correct types of motion in both motors.) Consequently, I tried using a larger power supply, 6V, in the form of 4 x 1.5V batteries in a battery holder, instead of one 4.5V battery.

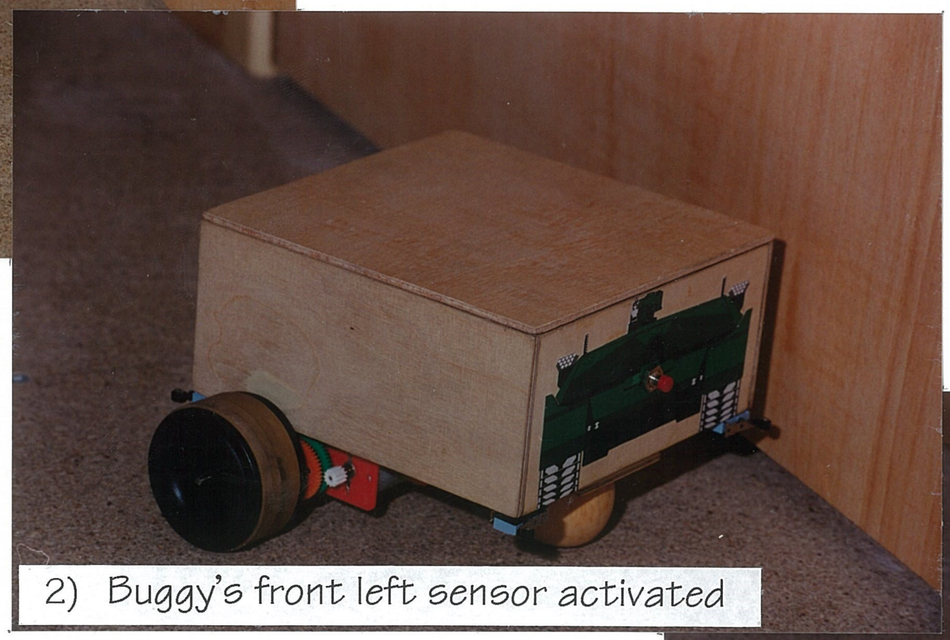
I also found that the buggy's momentum was sufficient to activate the switches on collision with a wall, although only if the switches were pressed full on. As the right motor operated marginally faster than the left, it was difficult to make the robot collide full on and procure a direction change. I decided to add four micro-switches, with levers and rollers, as additional sensors. These are more reliable than push switches (the combination of this amendment and the new battery seemed to overcome the previous problem altogether) and can also be activated from an angle. These were connected in parallel to the original push switches, using the two push switches as anchors, and worked amazingly well. They have the added advantage of working under collisions with very large angles, making the buggy significantly more 'user-friendly'.

The buggy was also making a tremendous noise, (which would have terrified any small child!), and so I sprayed ample WD40 onto the cogs in both gearboxes as lubrication. This dramatically quietened the motors to quite a manageable level, permanently as it would seem.

Buggy wall-banging in action



1) Buggy approaching wall

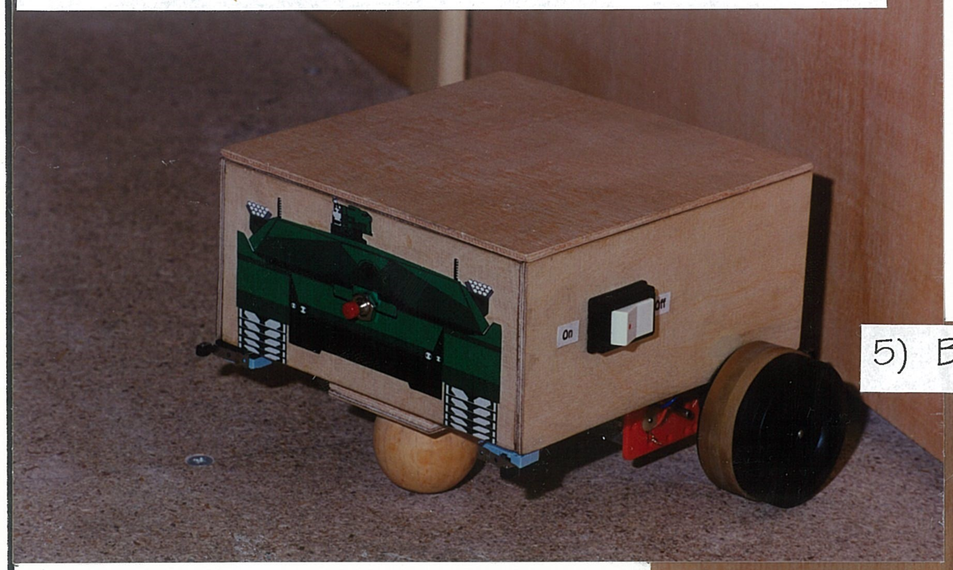


2) Buggy's front left sensor activated

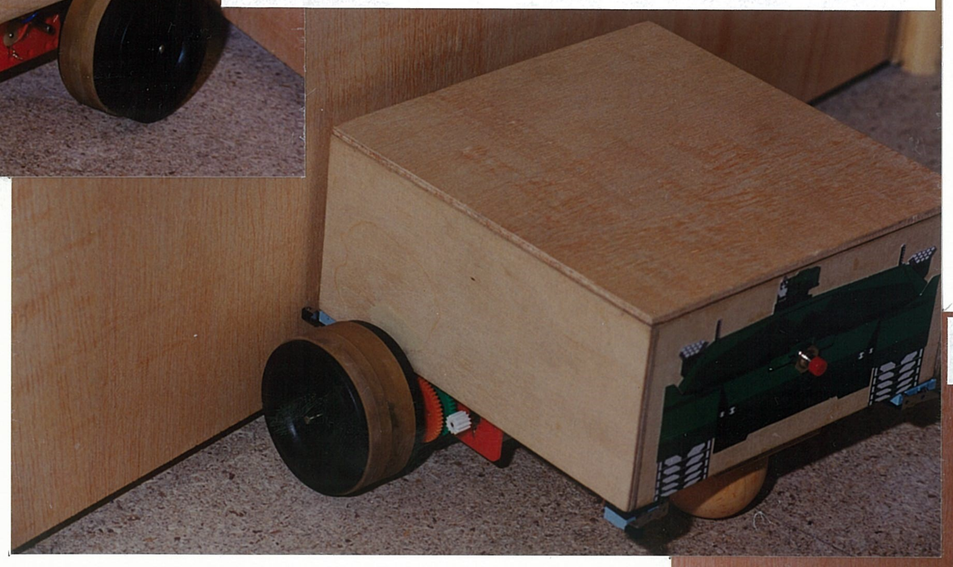
3) Buggy reversing clockwise away from wall

Testing

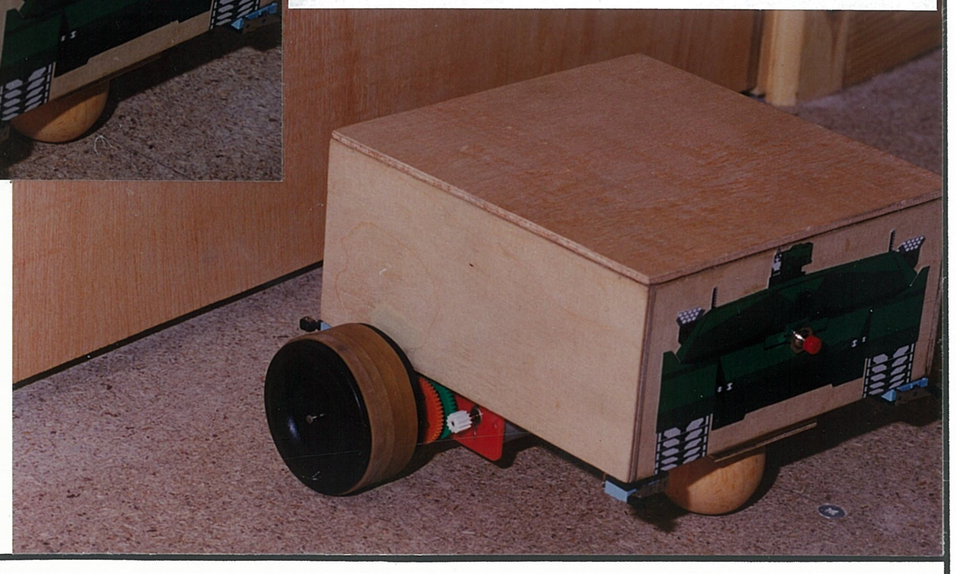
4) Buggy continues reversing, now towards wall



5) Buggy's back right sensor activated



6) Buggy withdraws away from wall



Testing

Evaluating the buggy's test performance

I tested the buggy's capabilities in a similar manner to the procedure demonstrated by the photographs: I aimed the buggy at a wooden door from a variety of angles, and set it into motion along the chipboard surface. I waited for the buggy to bump the door with a front sensor, subsequently a back sensor, and then proceed back the way it came.

Of a total of 50 tests, a large proportion of the time the buggy performed excellently, according to specification. However, the buggy did encounter various specific problems on a number of occasions:

- On 8 occasions a rubber band came loose from the wheels. Although this did not affect the buggy's action directly, it reduced the grip on one side, diminishing the force this side could exert relative to the other (thereafter the robot moved in a slight arc as opposed to a straight line), and of course, it looked untidy.
- On 5 occasions one of the wheels made contact with the wall before a micro switch could have been hit. Consequently the robot would become stuck without human intervention. However, this problem only occurred when the buggy was approaching the wall at a very acute angle, and could quite easily be avoided during normal use - it requires a very precise aim to procure such a problem.

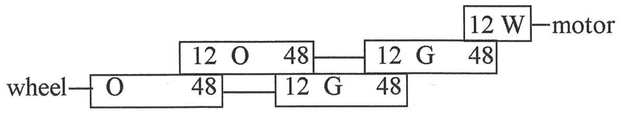
When I tested the buggy on some different surfaces, new problems emerged:

- On a particularly coarse surface it was usual that one wheel became caught in a rough patch and started to drag. This caused the buggy to end up turning in a wide circle.
- On a smooth carpet, the rubber bands picked up lots of unsightly fluff.
- On a tufty carpet the buggy would not function at all, probably because the front support was encountering too much resistance - I am sure that the motors were easily powerful enough.

Overall, it is clear that the buggy has certain limitations. However, these need not be apparent if the buggy is used in suitable circumstances, and then left to its own devices without human intervention. It is also obvious that the micro-switches would not have functioned if the buggy's obstacle were shorter than the height of the sensors. Though a limitation, this should never really be a problem as very few objects would be too short - even skirting-boards are of a sufficient height.

Gearing Analysis

The gearing arrangement is identical on both sides. Schematically it works as follows:



G = green gear O = orange gear W = white gear

Each box represents a whole gear, each line an axle.

(The green gears freely rotate, whereas the orange gears are stuck firmly to the axles; in this way both colours can rotate independently of each other, even though they are on the same axle.)

Each number represents the number of teeth in that end of the gear (each gear had two separate discs of teeth)

Thus the overall gear velocity ratio is

$$\frac{48 \times 48 \times 48 \times 48}{12 \times 12 \times 12 \times 12} = 4^4 = 256$$

That is, the gear on the motor axle must rotate 256 times in order for the gear on the wheel axle to rotate once.

According to the information on the back of the motor's packaging, 3V will procure 53 rpm. This implies that at 6V, the buggy's operational voltage, the motor runs at 2 x 53 = 106 rpm.(In fact, 107 rpm seems more accurate by similar analogy to the figure for 1.5V and 4.5V.)

The diameter of the wheels is 5.5cm. Therefore circumference = π x diameter = 17.28 cm.

$\Rightarrow$ velocity = 17.28 x 107 cm / min = 1849 cm / min = 31 cm / s

However, this would be the velocity of the buggy if the motors had zero load, that is, no weight to the buggy and no friction between the gears.

By actual measurement, it appears that the actual velocity of the buggy is only 5 cm / s. Thus the motors are operating six times slower than they would without load. This is not very efficient, although the buggy's velocity is ideal in practical terms.

Costing Evaluation

In my market survey, it emerged that most people would be prepared to pay around £20 for the toy for which they had previously opted - a maze-solving robot in the majority of cases. A small number of items, namely plastic sheeting, push-button switches, wire and circuit board, were available from school, hence these do not figure in my costing, and, at any rate, I do not know how much they cost.

The approximate cost of components featuring in my final product figures as follows:

Item	Expenditure (£)
Plywood	3 - 00
Relay x 2	5 - 50
Micro-switch x 4	5 - 00
Rocker switch	1 - 00
Battery holder & batteries	2 - 50
Geared motor x 2	16 - 00
Wheel x 2	2 - 50
Total	**36 - 50**

I have clearly exceed my target by about £16 - 50. However, this is really quite unavoidable considering just how expensive both the motors were - both completely necessary to provide sufficient power to drive the buggy. Of course, when my survey participants specified this price, they were thinking relative to high-street prices, for products which are usually mass-produced nation-wide. I believe that my total costing would duly diminish if I were to produce the buggy in bulk - the components would be cheaper and the wastage would be less.

Of course, I have spent even more money on components unwanted in the final product. These are, namely, four motors, two batteries, two wheels, gears and axles. Though considerable, these outgoings would not be necessary if the buggy were ever produced again, because I have learnt from my mistakes so that they would never get repeated. Also, not specified, is the cost of the sodium hydroxide and electricity for computer usage and tool operation. These are both paid for by the school, minimal though they were. Of course, if I were to mass-produce the buggy myself, I would have to pay for absolutely everything out of my own pocket!

Evaluation

Final evaluation

First and foremost, my toy thrilled my 8 year old niece no end, which was unequivocally what I had set out to do. I am sure that the toy has been such a success with her because it functions properly and reliably. However, in order to produce a fully operational toy I have had to compromise some of my original aspirations, mainly that of producing a small and compact buggy - it is much larger than I would have preferred.

Consequently it would be impractical to construct a maze suitable for navigation by the buggy (in any case I believe that the turning algorithm is too simplistic to take the buggy to the centre of any standard maze). I am also slightly worried that the toy is not totally child proof - the levers on the micro switches and tank decals could be easily torn off - and not totally child safe, because it is heavy enough to cause pain to a young child if dropped.

Still, the buggy seems to excel in navigating simple obstacles strewn around a flat surface - it is pleasing that the momentum of the buggy is sufficient to activate one of the micro switches on collision with a wall or obstacle (notably this was rarely the case before the addition of micro switches, except when a full-on impact was involved).

All in all this project has been a definite success, completed with ample time to spare.

Evaluation