Crafting Tangible Interfaces for Human Digestion: Unpacking the Research through Design Prototyping Journey

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ABSTRACT

This pictorial unpacks the prototyping journey of *Digestive Tumble* - a tangible system that demonstrates the processes involved in the human digestive system. The system aims to support awareness of our digestive processes and help users to make informed decisions about their dietary choices. *Digestive Tumble* consists of nine modules, where the modules visualise a unique stage of the digestion. The system represents the digestion of five major food groups: grains, meat, vegetables, fruits and dairy through colourful tokens. Users interact with the system by inserting tokens representing their meal. These tokens transform into colourful beads, which then traverse through different modules to show the digestion of the given meal. We reflect upon the steps involved in visualising an internal bodily process through a tangible system. We hope that our design reflection will inspire future systems on visualising other internal bodily processes to support body learning through everyday reflection.

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Authors Keywords

Digestion; Human-Food Interaction; Tangible Interaction

CSS Concepts

• Human-centered computing • Human computer interaction (HCI) • Interaction systems and tools

INTRODUCTION

"You are not just what you eat, you are what you absorb." - Thais Harris.

The human digestive system is one of the most important systems in our body [4]. It plays a vital role in converting food into nutrients, which the body then uses for energy, growth, and cell repair. Understanding the digestive system is the first step in raising interest in topics related to gut health and helping people to understand how their dietary choices impact their health and wellbeing [23].

While there exist several textbooks and websites describing the mechanism of our digestive tract and the factors involved, these mediums offer a static mode of learning where visualizing the operation of the digestive tract and movements of the food is difficult [3,35]. To overcome this, researchers have designed physical [14,15,28,43] and digital [1,7,13,24] replicas of the digestive system to support awareness through interactions. For example, Perkins e-learning program utilizes a series of tactile visualizations such as Knitted Digestive System [15] to help the visually impaired people understand the arrangement, sequence and structure of the digestive organs [14]. Body Odyssey [7] is a multimodal virtual reality based experience that allows individuals to learn about the digestive organs by letting them crawl inside the human body and explore the organs through visual, tactile, and auditory sensations. InsideOut [24] explores a playful representation of the digestive tract through the ingestion of imaging capsules and representing the data on an iPad. Finally, a large model of the human digestive system is also displayed at the MONA Museum in Australia [5] that shows the digestion of food from intake to excretion with realistic visuals and smells.

These works however, offer general information related to the human digestive system with which an individual may not be able to relate on a personal level. Moreover, it could also be difficult to apply such factual knowledge in an everyday routine because of the subjectivity and diverse eating practices of any individual [37,38]. Besides, these works focus on creating awareness about the anatomical structure of the digestive tract, and give less emphasis on the processes that happen inside one's digestive tract, which we consider as a missed opportunity. Understanding different processes may help in understanding how different foods get digested, which in turn could prompt individuals to eat a more diverse diet. As such, there have been limited attempts on representing digestive processes for everyday reflection, which we explore through *Digestive Tumble*.

In this pictorial, we present *Digestive Tumble*, a playful tangible system that visualises the processes of the human digestive tract. The system highlights the differences in digesting different food items like fruits, vegetables and grains. Our interest in developing a tangible system of the human digestive system stems from the prior literature [6,30,34] that suggests the benefits and opportunities of using tangible user interfaces. For instance, studies suggest that tangible interfaces take advantage of the connection between body and cognition, and facilitate tangible thinking, which means thinking through bodily actions, physical manipulation and tangible representations [21]. By externalising the internal processes of digestion through a tangible system, we aim to provide individuals opportunities to discuss their dietary choices with others without any stigma, and encourage balanced and diverse diets through both self- and shared reflection. We however, acknowledge that human digestion is a complex topic and one's digestive health is influenced by a variety of factors that include the user's lifestyle, microbial exposures and genetics [31]. *Digestive Tumble* is a simplified version with a dedicated focus on demonstrating the internal digestive processes for different food groups.

This pictorial makes two contributions: Firstly, through *Digestive Tumble*, we extend the HCI literature on body learning through tangible interactions [15,24,25,28]. To the best of our knowledge, this is the first system that visualizes the internal digestive processes to support reflection on our dietary decisions in everyday routine. Secondly, we reflect on our design process and highlight the key steps of creating a simple yet playful physical model of the human digestive system. These insights might also be useful for designers in creating interactive models for other complex human systems like respiratory and reproductive systems. Owing to the benefits that physical models offer [2,27,36], we envision more explorations like *Digestive Tumble* for changing the future of everyday reflection.

DESIGN GOALS

1. Simplifying digestion - Our first aim was to visualise the invisible processes of the human digestive in a simplified manner. We wanted to present information about the differences in digesting different food items and the processes and transformation of food involved in the digestion. We took inspiration from the analogy of 'our *body as a factory*' and '*organs as machines*' [10,33] to develop a tangible system for the human digestive system (refer Figure 1). Our digestive system, metaphorically could be thought of as a factory, where different digestive organs work together to break the food down into smaller pieces, chemically alter it using the digestive juices, extract the right nutrients from the food while discarding the waste. The resemblance to how a factory operates inspired our choices of visualising the digestive processes.

2. Personal relevance - Instead of providing generic representation of digestion, we focussed on creating a system that is relevant for personal use. Our aim was to offer visualisation of the digestion of different meals consumed in a day, so that users can reflect on their dietary choices.

3. Shared understanding - Our next aim was to support shared understanding of the individual digestive system. Hence, we focussed on making a tangible representation of digestion that can facilitate shared learning through physical interactions [15,28,43]. By externalizing our body organs and placing it in a shared setting at home, we aimed at creating a shared understanding of one's digestive processes, where family members could reflect on the 'how' and 'why' of each other's dietary choices. We took inspiration from playful tangible visualizations [20,44] to create a system that does not remain purely educational rather supports playful methods of learning a complex topic.

4. Glanceable feedback - Digestion is a slow process and we aimed at mimicking this slowness in our design. Our final aim was therefore to create a glanceable reflection tool [9] that does not require the continuous attention of users, instead can work silently in the vicinity. Users can check the status of their digestion as and when they want similar to checking time in a clock. In pursuit, we took inspiration from the existing works on 'slow design' and 'slow technology' [11,12,29] to support deeper reflection on our dietary choices. Slow designs and slowing down key aspects of an artifact have proven to create more meaningful and mindful interactions with artifacts [11].

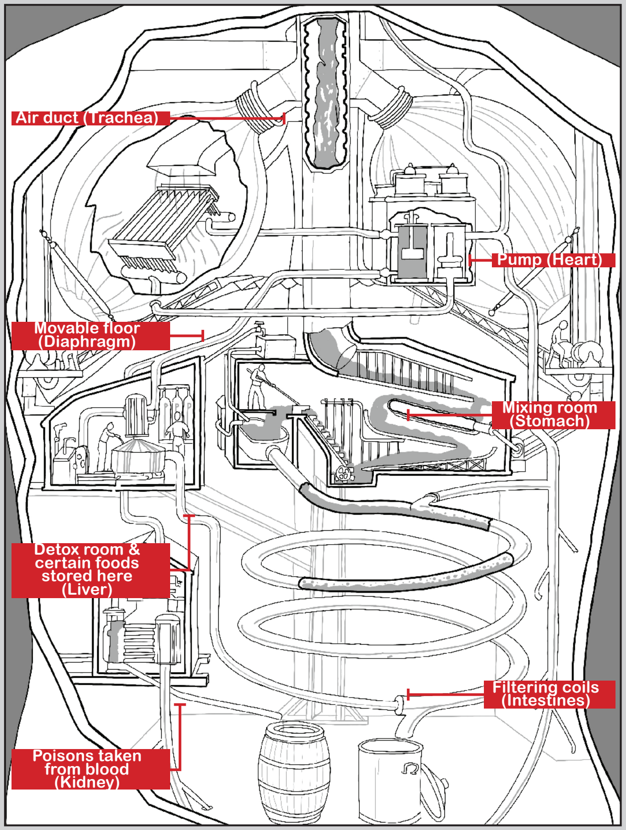

Figure 1: Conceptualization of the human body as a factory with different organs functioning like machines to keep the body alive. The illustration is adapted from The Miracle of Life published by Odhams Press, London, 1940 [39].

DIGESTIVE TUMBLE

Digestive Tumble is a tangible system that aims to create awareness of the complex activities of the human digestive system and foster self-reflection on one's eating practices. The design of *Digestive Tumble* is inspired by popular games like Turing Tumble [45] and Tetris [46], where objects fall from top to bottom on the game interface, similar to the way food travels through the digestive tract. This synergy also inspired the name *Digestive Tumble* that points to the tumbling effect, i.e., the downward motion of the food inside our digestive tract.

Digestive Tumble visualises different stages of the human digestion process namely, feeding, chewing, swallowing, chemical breakdown, mechanical breakdown, nutrient absorption, fermentation and excretion. The system (532mm in height X 276mm in width) has nine modules, where the first eight modules represent a different stage of the digestion process and the last module provides users an opportunity to reflect on the different meals of a day (Figure 2). The system provides information about the differences in digesting different food items in terms of time and processes. Please refer to the Appendix for the detailed description of each module.

Digestive Tumble represents the digestion of five major food groups: grains, meat, vegetables, fruits, and dairy [26]. These food groups are represented through different colored circular acrylic tokens. During digestion, these food groups are converted into macronutrients like proteins, fats and carbohydrates. In *Digestive Tumble*, these macronutrients are represented through different colored plastic beads. These beads travel through the system at different rates depending upon the meal consumed by the user. For instance, since vegetables and fruits are quick to digest, the corresponding beads would traverse fast through the system whereas the beads that correspond to grains, meat and dairy will follow slow digestion rates.

The system is designed to be used in home context and supports everyday reflection on an individual level. The user can place the system in the nearby vicinity. The system can serve as a guide on when to have the next meal or act as a visual food diary for a day. By periodically glancing at the system, the user can know the latest status of digestion for their consumed meal.

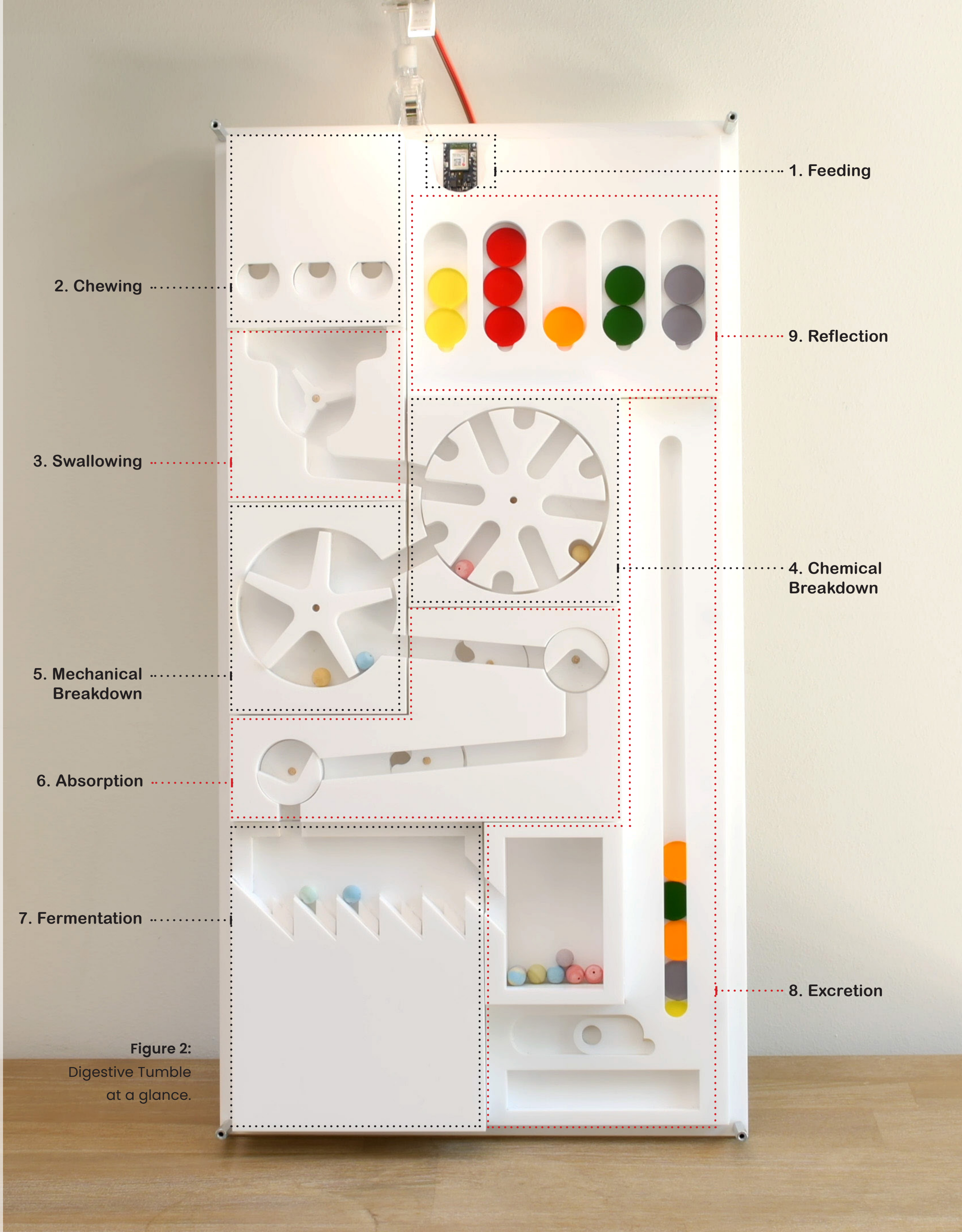

Figure 2: Digestive Tumble at a glance.

DIGESTIVE TUMBLE IN ACTION

We explain the working of *Digestive Tumble* through a scenario: Consider Robert has just consumed a plate of tomato and cheese pasta for his lunch and wants to reflect on how the pasta gets digested through *Digestive Tumble* (refer Figure 3 for a stepwise process).

1. Robert first reflects on the food groups corresponding to his tomato pasta. The meal contains pasta, tomatoes, and cheese, which equates to grains, vegetables, and dairy food groups. He then picks up the yellow, green and grey tokens from the token plate, and inserts them into the Feeding module one after the other in any order.
2. The BLE sensor attached in the Feeding module detects the colour of the inserted tokens and triggers the Chewing module to release the corresponding number of beads. The three tokens are transformed into a total of 9 carbohydrates, 6 protein and 2 fats beads. The inserted tokens traverse to the excretion module for later collection.
3. The coloured beads then traverse through the Swallowing module and reach the Chemical breakdown module.
4. Chemical breakdown module consists of a rotary panel that rotates all the beads and bounces them on the inner wall, representing the coating of chemical enzymes along the stomach lining.
5. The beads then move to the Mechanical breakdown module, where the beads are mixed around and knocked against each other to represent the structural disintegration of food in the stomach. This act of knocking generates a pleasant sound that serves as a subtle audio feedback on the progress of the digestion.
6. The beads then traverse to the Absorption module, where some of the beads are randomly removed along the pathway to represent the absorption of nutrients into the bloodstream.
7. The remaining beads then traverse to the Fermentation module, where they are poked up and down by a zig-zag panel. This poking mechanism represents the fermentation of the remaining food particles that were not absorbed into the bloodstream.
8. The Excretion module stores all the beads once the food has gone through the entire digestive system. Robert can release all the beads by pushing the slide, representing the excretion through the rectum. He can then stack these beads into the Chewing module for further use.
9. Robert finally collects all the tokens from the Excretion module and stacks them in the Reflection module. He can also create a visual food diary by stacking tokens from different meals of the day, and can reflect on his food choices.

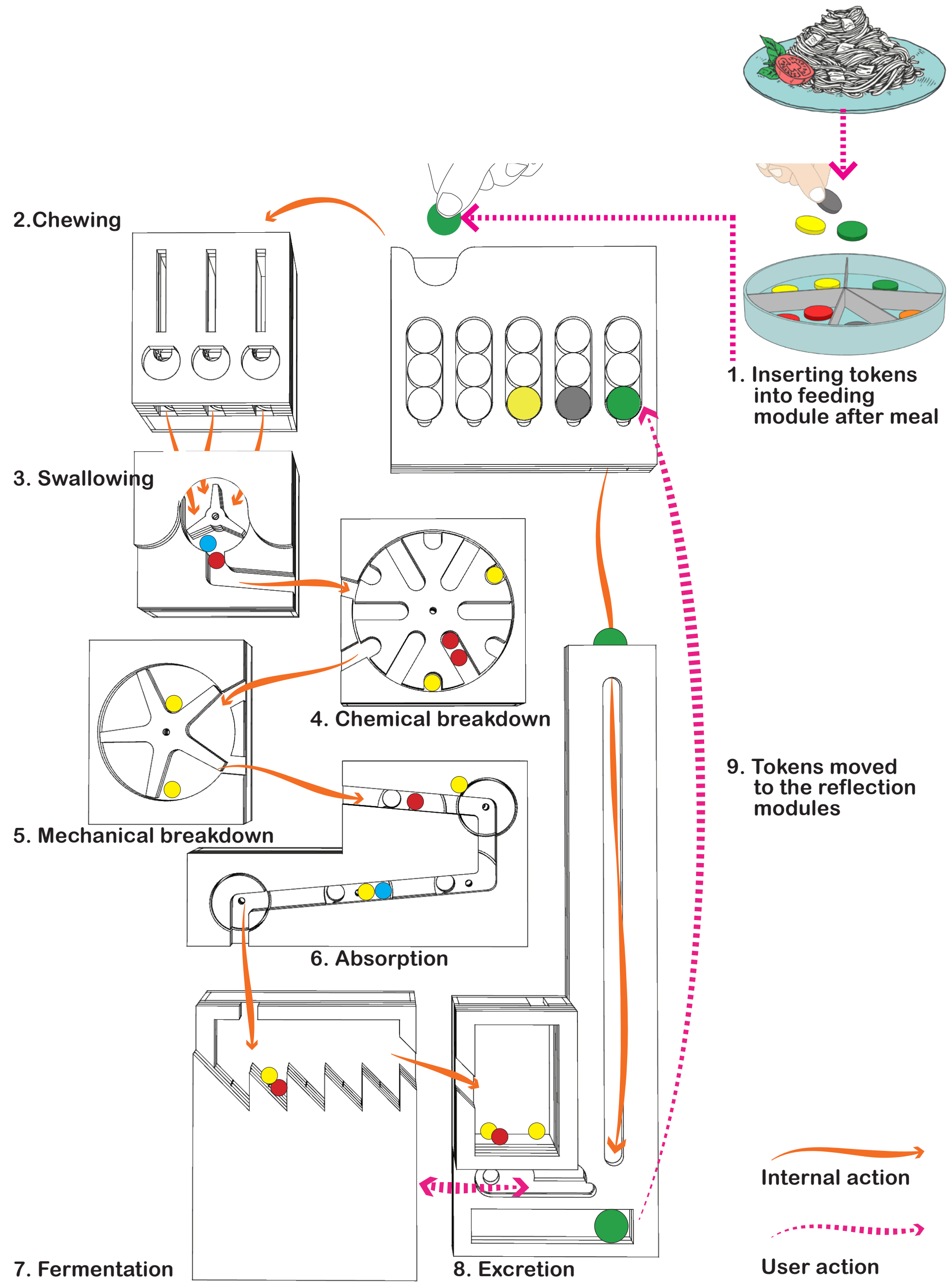

Figure 3: Diagram shows how the tokens and beads traverse through each module.

DESIGN PROCESS

We employed the Research through Design approach [41] to develop *Digestive Tumble*. The design was led by a team of industrial designers and computer scientists with expertise in digital health and interaction design. The system was iteratively designed over a period of 10 months, where different iterations were trialled with the lab members. The design process involved exploration of different materials, hardware schemas and group discussions that prompted iterations of the design goals as well as the design. Owing to the space constraint, below we describe the key aspects of our design as they emerged during the design process. While the design process followed a complex process, where different concepts and modules progressed in parallel, we present them in a sequential order for simplicity.

1) REPRESENTING FOOD GROUPS

When we started this work, our first goal was to decide on how to represent different types of foods. We initially considered representing all kinds of foods. However, representing the diverse variety of food in the system would have added unnecessary complexity of recognizing and tailoring each food individually. Instead, we focused on representing the five core food groups and their portions as described by Australian Dietary Guidelines [26] (refer Figure 4): grains, meat, fruits, vegetables and dairy. Drawing inspiration from vending machines, we decided to use circular tokens of different colors to represent each food group. We also created a token plate (refer Figure 5) resembling categorisation of food as defined by Australian Dietary Guidelines. Each token is made of acrylic and is 24mm in diameter and 2 mm in thickness. We carefully chose vivid colors so that they are easy to distinguish both by the users as well as the system. One token here represents one serving (i.e., one cup) of the given food group. In the future, we plan to build a smartphone app that can do a more accurate conversion for all kinds of meals and also to assist users in breaking down their meal in terms of five food groups.

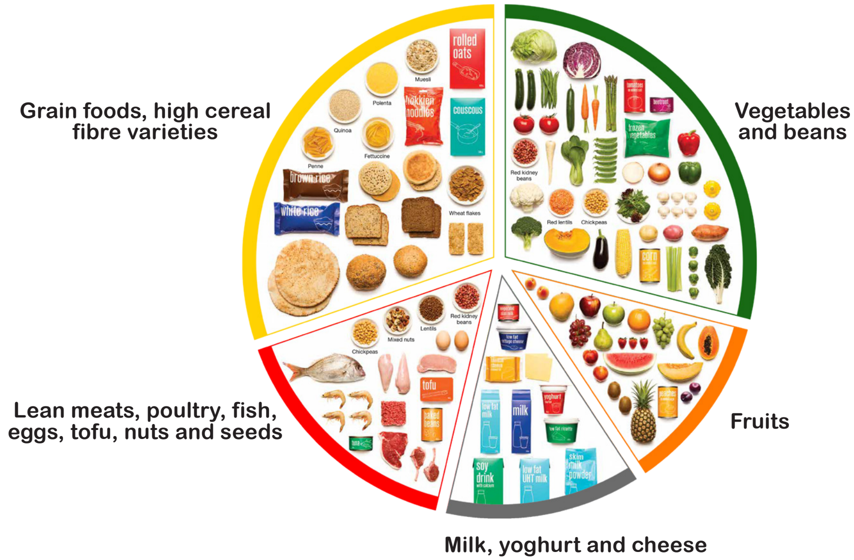

Figure 4: Categorisation of food as defined by Australian Dietary Guidelines [26].

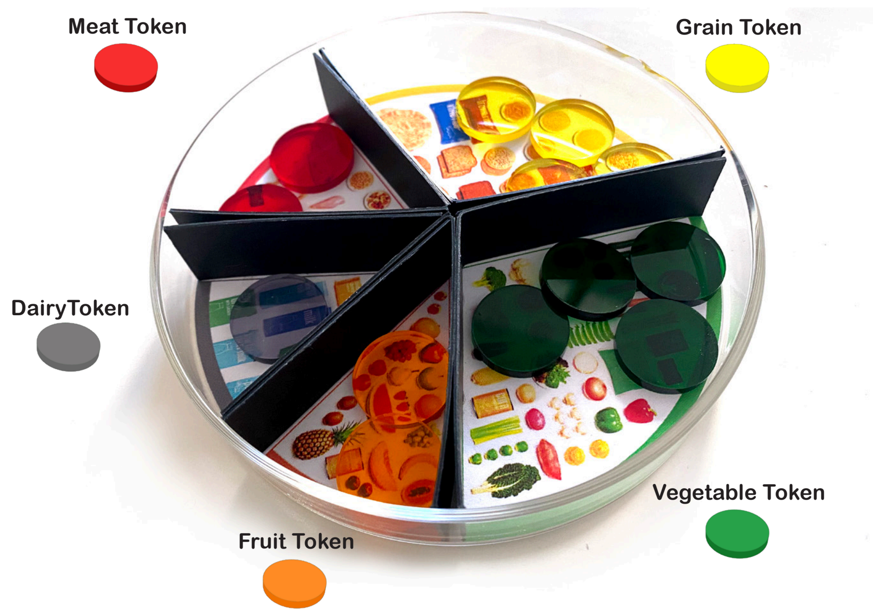

Figure 5: We created a token plate to represent the food categorisation.

2) REPRESENTING THE DIGESTION RATE

After deciding on the food groups, the next important question was to represent the digestion rate. Deciding the digestion rate of a meal was challenging, because it varies based upon the composition of the meal [42] as well as users' eating habits [22], for example, fast eaters vs. slow eaters. Also, one meal may consist of one or more food groups. However, for simplicity, we focused on the food composition of the meal against other factors.

We learnt from the existing resources [47,48] that a fruit plate takes about an hour to digest while meat can take up to three days to digest. Drawing on these insights, we mapped each food group to a specific digestion rate to calculate an approximate duration of digestion for a meal (Figure 6). Since fruits and vegetables are high in fibre, they speed up the digestion rate, hence we categorized them as subtractive tokens. On the other hand, grains, meat and dairy slow down the digestion due to their complex molecular structure, hence they are categorised as additive tokens. The value of different food groups are added or subtracted to calculate the overall digestion rate for a meal.

In *Digestive Tumble*, we have set a default time of 8 hours (480 mins.) as the digestion rate of a meal. This time changes based on the combination of food groups present in the meal and it is controlled by a stepper motor mounted at the back of the system (refer Figure 8). The motor runs with a default step angle of 1.8 degree per 5000 millisecond (ms). However, the motor is speeded up or slowed down depending upon the tokens inserted.

Considering the previous example of tomato cheese pasta, if the user inserts grain, vegetable and dairy tokens to reflect on his meal, the system will add 120 minutes for the grain, subtract 40 minutes for the vegetables and add another 90 minutes for dairy, making the total duration to 650 minutes to run the system (refer Figure 7). Table 1 represents the time assigned to each food group, which guides the motor speed. For example, a fruit token will reduce the rotatory time of the motor by 800 ms (i.e., 5000-800 = 4200ms), hence will speed up the motor. The system will calculate a cumulative time for all the tokens inserted to represent the digestion rate of the given meal.

We note here that the duration is an approximation and digestion rate can differ based on users' genetics, age, sedentary lifestyle as well as how and in what combination the food is consumed. In the current prototype, we have not included the influence of these factors on digestion rate for simplicity, but in future versions, we aim to offer customization options for users to tailor the speed of the motor based on their lifestyle.

Food Group	Fruit	Vegetable	Dairy	Grain	Meat
Time (miliseconds)	-800	-1000	+1000	+1200	+1500

Table 1: Time approximations for different food groups.

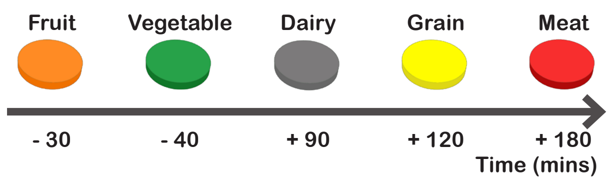

Figure 6: Items from different food groups take different time to digest. Meat takes the longest time to digest whereas fruits take the least time.

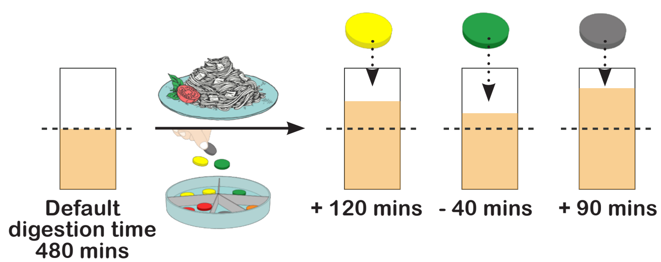

Figure 7: Digestive Tumble will run for 650 min. to show the digestion of a plate of tomato cheese pasta.

Figure 8: Digestive Tumble represents the digestion rate of different meals through a stepper motor.

3) REPRESENTING FOOD TRANSFORMATION

After finalizing the food groups and digestion rate, we next looked into how to represent the food transformation. Food goes through multiple transformations (refer Figure 9) during the overall process of digestion. The digestion process starts when we put food in the mouth for feeding ourselves. We then chew the food in our mouth, where it gets mixed with the saliva, and the transformation of the food starts from here itself. Here, food is broken down into macronutrients such as fats, proteins, and carbohydrates before being swallowed into the stomach. In the stomach, the food is further disintegrated into smaller particles through chemical and mechanical breakdown processes before being emptied into the small intestine where nutrient absorption takes place. The remainder of the food is then moved to the large intestine, where fermentation takes place. This process is facilitated by bacterias that support the breakdown of waste. The final stage of the digestion process happens in the rectum, where the waste products are stored and eliminated out of the body. In a nutshell, every consumed food item gets transformed into different ratios of micronutrients, i.e., carbohydrates, proteins and fats. We referred to the Diabetic Exchange System Database [8] and created an estimation of macronutrients for different food groups as shown in Table 2.

To visually represent the transformation of food groups to macronutrients, we initially thought of using the Gobstopper Candy [49], taking inspiration from the marble balls as used in marble machines and STEM games like Turing Tumble [45]. Our idea was to transform the candy along the different processes of digestion to mimic the food transformation as shown in Figure 10. We were also inspired by the positive influence of using food materials on user behaviour and attitude [16,19]. However, we encountered technical issues when changing the physical state of candies inside the system. Owing to issues related to food handling (hygiene), food waste and blocking of the system with molten candies, the idea was discarded. We also discarded the idea of physically transforming an item, from solid state to powder (refer Figure 10). Instead we relied on conceptual transformation where the circular tokens representing food groups get transformed into beads that represent the macronutrients. We decided to use 10mm diameter jewelry beads of different colours to represent the macronutrients (refer Table 2).

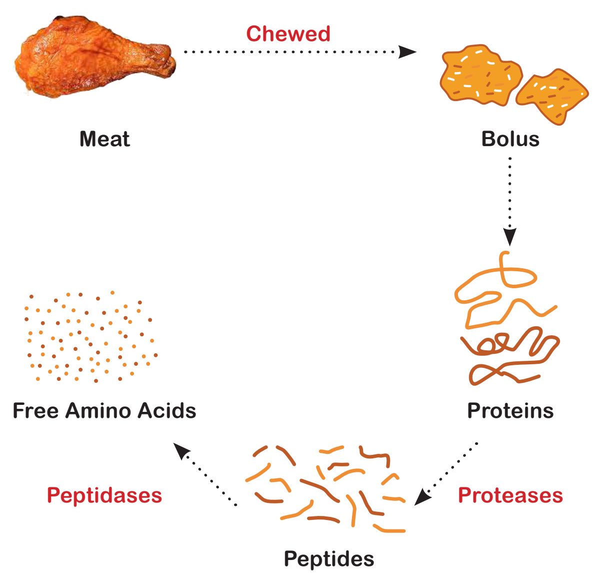

Figure 9: Transformation of meat in the digestive tract during digestion.

Figure 10: Chocolate candy changing its shape to illustrate different digestive processes.

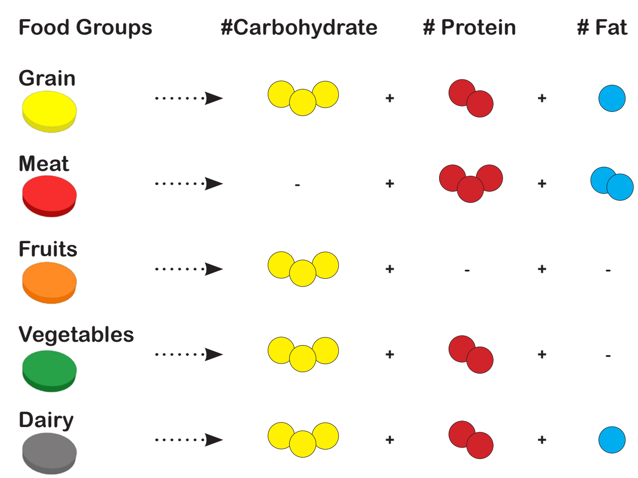

Table 2: Conversion of the main food groups into macronutrients. We allocated 0-3 macronutrient beads for each food token, with 0 being nil and 3 being the most in the particular nutrient.

4) REPRESENTING THE MECHANICAL PROCESSES OF DIGESTION

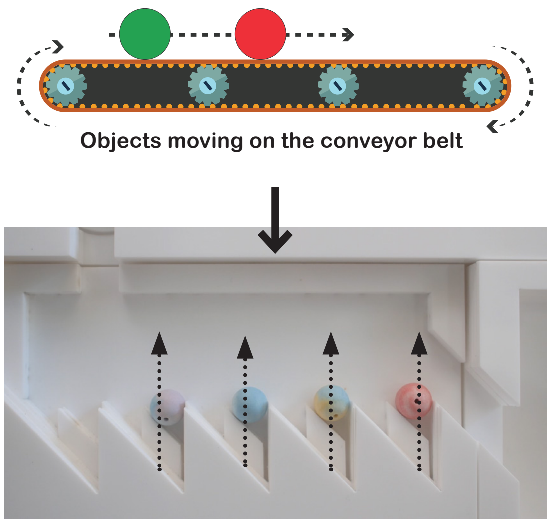

Figure 11: Fermentation module utilizes a zig-zag conveyor belt to move beads.

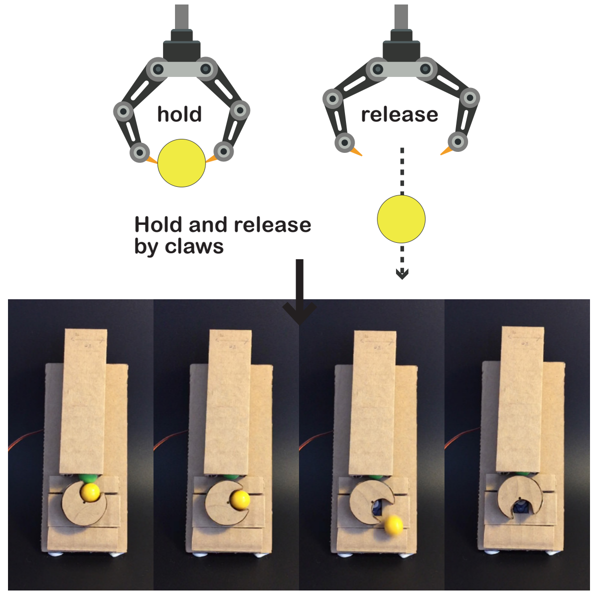

Figure 12: Chewing module uses the hold and release mechanism to release beads.

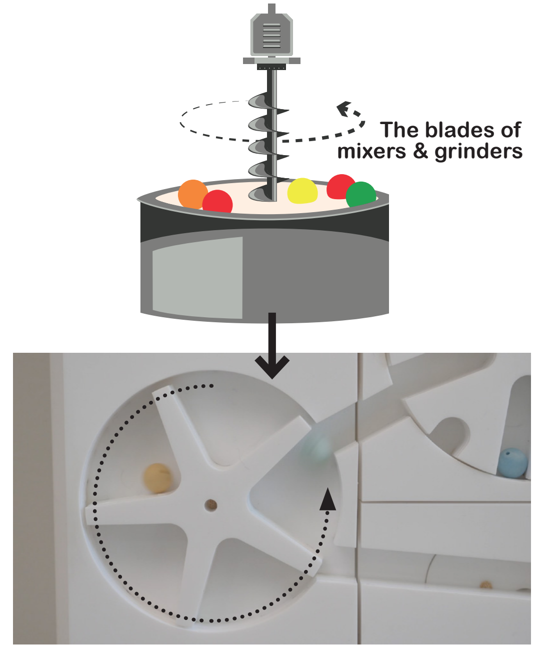

Figure 13: Mechanical breakdown module utilizes the mixer blades to show the breakdown of food.

Certain processes in our digestive system involve the breakdown of food into smaller pieces with or without any fluids like acids and enzymes [40]. Chewing, fermentation, chemical and mechanical breakdown are all examples of mechanical processes. We thought of including fluid components in our design but later discarded the idea to keep the design simple and hygenic. Instead we relied on industrial metaphors to communicate the essence of each process. Below we describe our thinking behind the four mechanical processes.

Fermentation is the enzymatic decomposition of those food particles that are not yet absorbed into the bloodstream. The process involves microbes getting attached onto the nutrients and fermenting them. We represented this act of microbe attachment by a poking mechanism. We designed a pushing mechanism that alternatively moves up and down to simulate the poking act (refer Figure 11). The zig-zag movement is built upon the conveyor belt mechanism, where the food moves in a horizontal direction but with a delay caused by the fermentation process.

Chewing process breaks down the chunks of food into smaller nutrient particles for digestion. We represented this transformation of food into macronutrients by changing the food tokens into beads, which are smaller in size than the tokens. Every token is assigned with a defined set of beads (refer Table 2). We used the hold and release mechanism to streamline this process of conversion and release of beads (refer Figure 12). The module consists of three storage spaces that store the coloured beads. At the back of each storage space, a servo motor (Tower Pro Micro Servo 9g) is attached that releases the beads according to the token inserted.

Mechanical breakdown involves continuous mixing, compressing and shearing of food particles to break the food down into smaller particles. We visualised this process by designing a mixer-like blade that spins the beads, knocking them against each other to represent the mechanical disintegration of food (refer Figure 13). The audio feedback of the beads knocking each other also creates an illusion of the beads breaking down into smaller pieces.

5) REPRESENTING THE MOVEMENT BASED DIGESTIVE PROCESSES

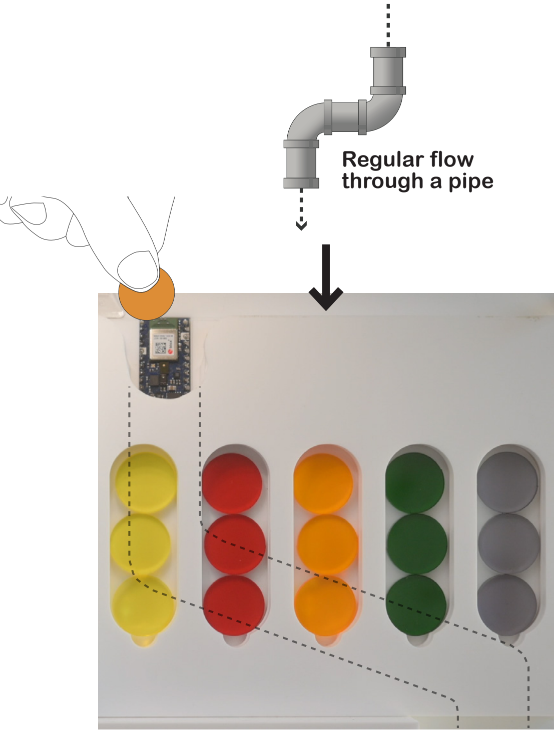

Figure 14: Feeding module consists of a pipe shaped tract.

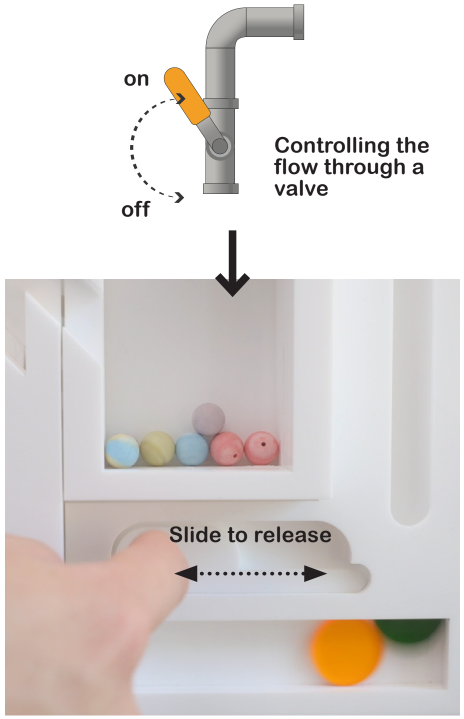

Figure 15: Excretion module consists of a slider to control the flow of beads.

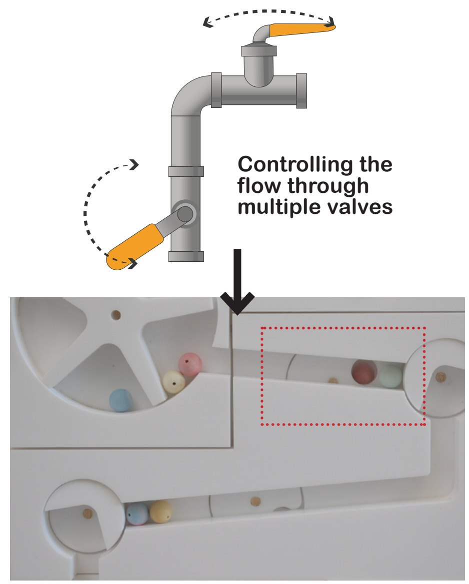

Figure 16: Working of the Absorption module.

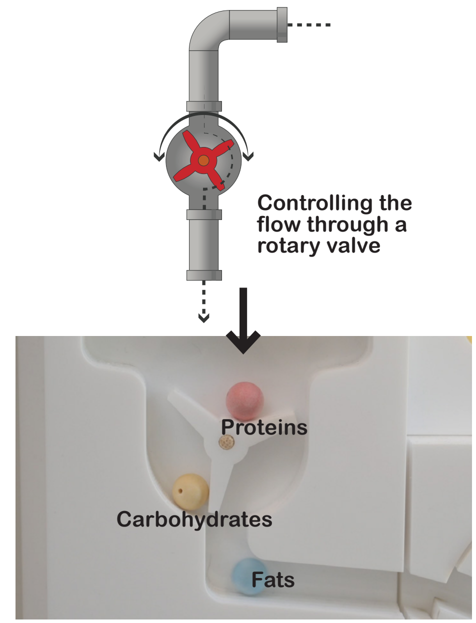

Figure 17: Swallowing module utilises a rotary mechanism to control the flow of beads.

Besides transformation, certain processes in our digestive system involve movement of food from one organ to another. This movement is supported by involuntary wave-like muscle contractions, referred to as peristalsis wave motion [32] and it is used by four processes, namely, feeding, swallowing, absorption and excretion. Initially, we considered using a series of actuators to recreate the peristalsis wave motion for these processes. However, this idea requires several actuators for creating only one wave motion - which we felt was unnecessary. We then focussed on the 'involuntary' process of peristalsis motion and abstracted it as 'not needing energy' to activate the process. In pursuit, we used different commonly seen industrial mechanisms to visualise these processes.

Feeding involves the act of putting food into the mouth. To represent this process, we designed the module with a tract (resembling a pipe), where the user can insert tokens (refer Figure 14). The tract will then lead the tokens into the next module.

Excretion represents pushing the waste food particles out of the body through rectum. The module takes inspiration from a valve and allows the user to manage the beads through a slider (refer Figure 15).

Absorption of nutrients is another process that involves movement of food nutrients from the small intestine into the bloodstream. We demonstrated this act through removing beads from the module by making holes at certain locations along the tract (refer Figure 16). These holes open at defined intervals, similar to the valves in pipes. Beads falling in these holes mimic the act of nutrients being absorbed into the bloodstream.

Swallowing is the act of pushing the food down from the mouth to the esophagus. The module consists of a rotating divider that rotates with the weight of beads to move the beads down to the Chemical breakdown module (refer Figure 17). The rotary valve helps in streamlining the flow of beads, thereby avoiding any choking issue.

6) REPRESENTING THE DIGESTIVE TRACT

The final aspect of our design was the representation of the digestive tract involving multiple organs that perform different tasks for digestion [40]. These organs are mouth for chewing, esophagus for swallowing, stomach for digestion, small intestine for absorption, large intestine for fermentation and rectum for excretion (refer Figure 18a). These organs follow a non-linear arrangement and are compactly arranged inside our body, e.g., small intestine is a 22 foot long tube that is tightly organised in a small place between the stomach and large intestine. Additionally, the shapes of different organs of the digestive tract vary from tubular to complex geometrical shapes.

We started by creating less detailed and abstract visualisations of each organ of the digestive tract with the aim to highlight the processes over anatomical structures (refer Figure 18b). During this activity, we learnt that some organs perform more than one process. For example, the stomach first helps in the chemical breakdown of the food and later gets involved in the mechanical breakdown. Also, multiple organs are involved in performing one process. Moreover, the processes are not linear and different processes happen in parallel.

We decided to break down the arrangement of organs into processes and represent these processes using geometrical figures such as square, rectangle and L-shapes (refer Figure 18c). We tried to represent the arrangement of modules as closely as possible to the arrangement of the digestive tract. For instance, we placed the chewing process at the top to represent the beginning of the digestion process, stomach module in the middle and the excretion process at the bottom to represent the end. But at the same time, we also focussed on representing the different processes independently through geometrical shapes.

All the processes involved in digestion are unique in their mechanism. Hence, we created a modular design for our system, where each process is represented separately by a module (refer Figure 18d). Each module has a tract that connects it to the next module. While all modules are joined to present the digestion process, users can also work with each module separately to understand how a specific process works out for the given food. The use of simple geometrical figures ensured that each process module remained intact into the base, as shown in Figure 19.

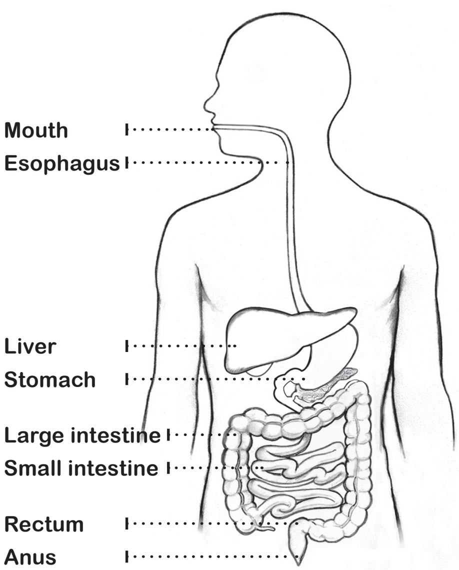

Figure 18a: Arrangement of different organs in the digestive tract.

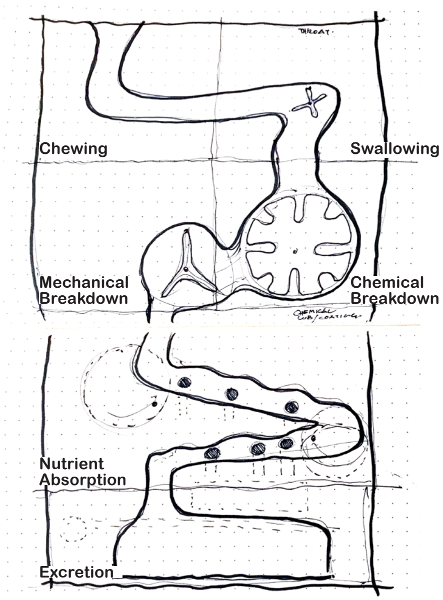

Figure 18b: Simplifying the digestive tract.

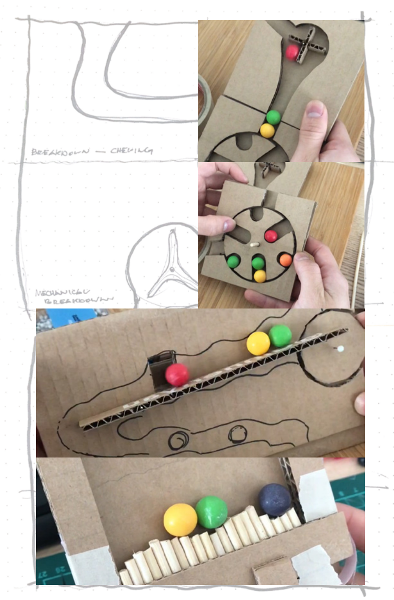

Figure 18c: Using geometrical figures to visualise the digestive tract.

Figure 18d: Making the design modular.

7) MAKING DIGESTIVE TUMBLE SUITABLE FOR HOME USE

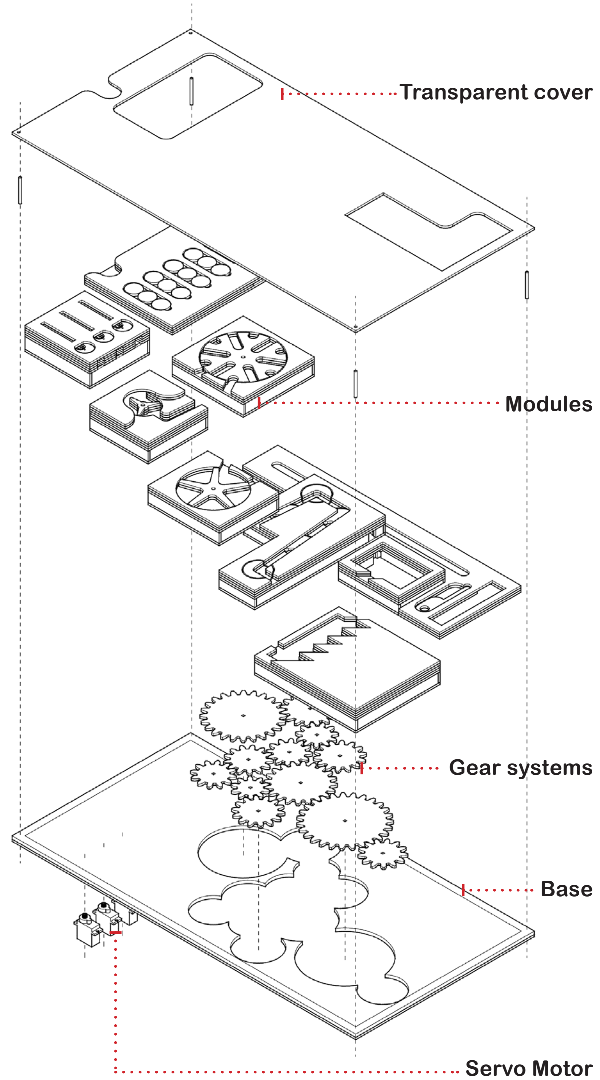

Figure 19: Digestive Tumble follows a minimalistic design, and utilises 12 various sized gears and 1 stepper motor to run all nine modules. The system is attached with a transparent cover to avoid spilling of beads and tokens and to keep all the modules intact.

We designed *Digestive Tumble* to work as a standalone unit at home and needs input only in the form of tokens. The system does not require any data communication through Bluetooth or Wi-Fi. The system follows a minimalistic use of electronics and runs mostly with mechanical gears. For instance, all the modules that have a rotating mechanism (except the Feeding module) work through a gear. The system consists of 12 various sized gears controlled by a stepper motor that runs via Arduino. We used AutoCAD software to design customized gears for each module. Moreover, we used GearGenerator [50] to visualise the correct direction of rotation for each gear so that all the modules could work as intended (see Figure 19). To avoid the issue of overheating of the stepper motor, we mounted it at the back of the model which is open and well-ventilated.

The system is packed with a transparent acrylic cover, which holds all the modules, tokens and beads together. The transparent cover has two defined cuts near the Reflection and Excretion modules to allow handling of the beads and tokens. There are no exposed electronic components nor the system makes use of any chemicals, hence making the system safer to use in everyday context. *Digestive Tumble* however, needs direct power supply to power the following three components: (i) Arduino Nano 33 BLE Sense used to detect the token colours, (ii) Stepper motor used to power the gear systems, (iii) 3 servos (Tower Pro Micro Servo 9g) to release the beads.

Accommodating varying lighting settings at home

Digestive Tumble utilises a BLE sensor to detect the colour of the token inserted. Accuracy of the colour detection however, depends upon the room lighting. We mounted a small LED light on the top of the system to provide consistent lighting to the BLE sensor, thus ensuring correct detection of tokens in different light settings (refer Figure 20).

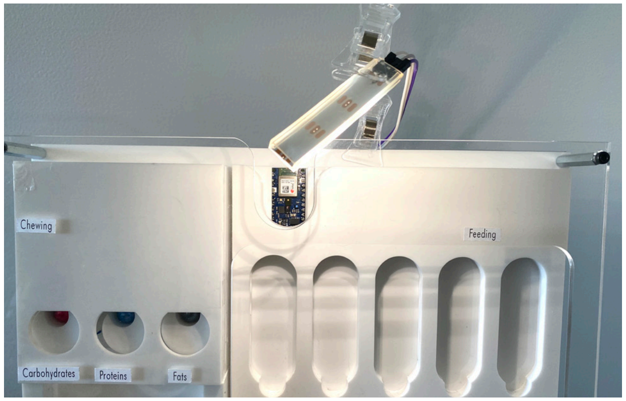

Figure 20: Digestive Tumble is attached with an LED light to provide consistent lighting to the BLE sensor.

FINAL REFLECTIONS

We presented the design of *Digestive Tumble*, a tangible system that aims to create awareness on the processes involved in the human digestive system on a daily basis. The system demonstrates how the food goes through different processes by using physical metaphors like tokens and beads. We reflected on our Research through design prototyping journey and described the key steps involved in visualising the invisible digestive processes through a tangible system. We described how we represented the composition of food through five food groups; how we represented the digestion rate of different food groups through industrial processes; how we represented the transformation of food through tokens and beads; how we represented the different mechanical and movement based processes through different industrial mechanisms; and finally how we represented the physical appearance of different organs and their connections through geometrical shapes. We envision that these steps may also help designers to visualise other bodily processes such as respiratory systems or reproductive systems through tangible systems.

We now reflect on the design goals that we formulated at the beginning of our design journey and describe how we achieved our goals.

Simplifying digestion: *Digestive Tumble* presents a simplified view of all the processes involved in digestion. We included a certain level of abstraction to simplify the complex digestive processes so that users can easily understand the processes. For instance, showing the chemical breakdown process through liquids or acids was not feasible for a system that is designed for home use. Instead, we showed the process of the chemical enzymes getting coated on the food through the rotational mechanism. Additionally, while the food changes its physical form in many ways during the whole digestion process, we took a simplified approach to represent the transformation of food through tokens and beads.

We have used an estimated digestion rate to demonstrate the digestion rate of different food groups like carbohydrate, meat, dairy, fruits and vegetables. We have also used approximations to define the macronutrients present in different food groups. These approximations are limitations of our system, and future investigations are required to make such systems more accurate. However, this level of abstraction was necessary to imbue an interest and easy understanding of the complex digestion processes. When we use abstractions, we hide the complexity of the actual processes and introduce new complexity. Hence, abstraction creates a challenge that users may not understand what each module represents for the first couple of interactions. However, previous works [17,18] suggest that understanding of abstract physical visualisations improve over time. Our next step is to conduct field studies of *Digestive Tumble* to understand the challenges and benefits of simplifying the digestive process.

Personal relevance and shared understanding: *Digestive Tumble* is designed to be used on an individual level by showing the digestion of food consumed by the individual at different times of a day. The individual inserts the tokens representing the consumed food into the system and observes how the food undergoes transformations across different modules (processes). While the system demonstrates the working of the digestive system for an individual, the placement of the system in the home environment will also invite opportunities for shared reflection. For instance, being present in the shared setting of a household, the system may invite conversations around the digestion process, food choices and overall health among the family members and beyond. Besides, the abstraction used in each module will also help people to talk about the bodily processes more openly. For instance, the excretion process does not contain the stigmatic details like colour, shape or odour of the stool, hence providing opportunities to discuss the processes both in general and in relation to their body. Discussing the digestive system such as the excretion, constipation or being gassy holds stigma and people do not talk about them freely. By externalizing the internal processes and putting them out on display, we provide a different perspective to reflect on one's digestion process.

Taking inspiration from the '*body as a factory*' concept, we used familiar metaphors of machines and industrial processes to communicate a preliminary understanding of the human digestive system. While this concept helped in creating tangible visualisations of the invisible bodily processes, it also made our understanding of the digestive processes limited. For instance, this concept considers every human body as the same, and there is no consideration of other factors like lifestyle, genes, microbiota, cultural upbringing and environmental factors. More explorations are needed to allow customisation of the system based on the personal factors. For example, an athlete with an active day can speed up the system working, whereas a user with a sedentary routine may slow down the system working. Future works can also explore the opportunities to increase the personal relevance of the system by visualizing the processes behind the common digestive issues like bloating, flatulence, burping and acidity.

Glanceable feedback: *Digestive Tumble* is designed in white colour and has no flashy components so that it can merge well in the home setting. While the modules of the system are white in colour, the beads are colourful to support glanceable feedback. The size of the system is also carefully designed so that users can glance at the modules from a distance to check the status of their digestion. *Digestive Tumble* mimics the slowness involved in the digestion processes and presents the digestion of a meal over a long period. For instance, the system takes up to 2-4 hours to show the digestion of a meal, where the time varies depending upon the food composition of the meal. *Digestive Tumble* aims to support slow reflection on our digestion processes. The tokens and beads support multimodal interactions (i.e., visual, tangible and audio) with the system. We hope that the multimodality, slowness and playfulness in interactions will allow deeper reflections on one's dietary choices, encouraging them to adopt a diverse diet.

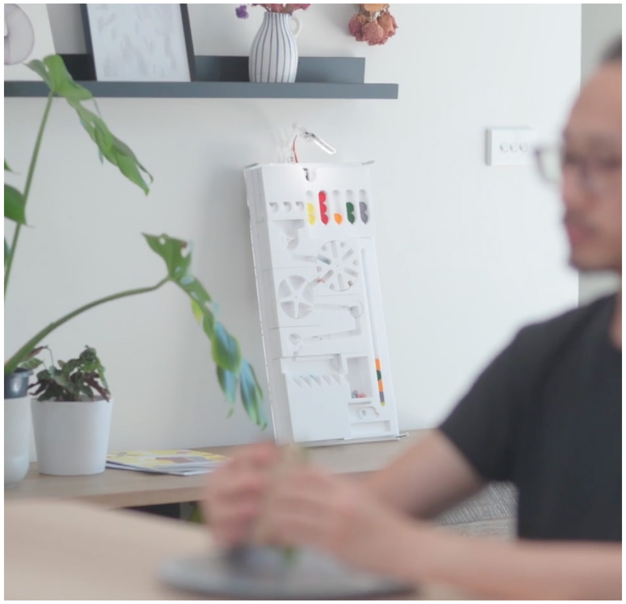

Figure 21: Digestive Tumble in the close vicinity of a user.

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