Evaluating Game Mechanics To Convey Complex STEM Concepts

Prototyping and iterating an online game about the body

Annie Conway
Digital Media Producer
Museum of Science and Industry, Chicago
Annie.conway@msichicago.org

Steven Beasley
Director, Digital Media
Museum of Science and Industry, Chicago
Steven.beasley@msichicago.org

Meaningful Play Conference
10.19.2012

The Exhibit

YOU! The Experience is a permanent exhibit at the Museum of Science and Industry, Chicago, that examines the connections between the mind, body, and spirit. Although it is an exhibit about how the body works, *YOU!* is not limited to a biomedical perspective; the exhibit also delves deeply into how the body systems interact with personal experiences and the conditions of the world we live in to make each individual unique.

In 2011, the Digital Media team at MSI began planning a suite of digital experiences that would extend the experience of the *YOU!* exhibit to users everywhere, and supplement the in-gallery content with deeper, targeted content for specific audience groups. These included:

- Would You Eat That?: A lightweight online game for kids and tweens
- Virtual Heart: An iPad app to explore the heart for adults and teachers
- Chew or Die: a food challenge mobile app for teens and young adults

The Game

NOT just another "edutainment" game about the body.

However, the Digital and Exhibit teams also wanted to create an interactive experience that tied all the information about individual body systems (circulatory, respiratory, nervous, etc.) in the exhibit together—one that would allow users to explore the body as a whole and understand how those systems interact. This experience would also allow us to feature more in-depth, scientific content on each individual body system to supplement the physical exhibit.

When looking at the available educational, interactive content about the body and health, we were surprised by how little of it there was, and how childish and templated it seemed. Most of these games seemed to be designed as very linear classroom activities, with little relation to the user's own body or lived experience. One of the only examples that offered exploratory play and a sense of the complex connections between body systems was Google Body. Both these good and bad examples guided the conceptual development of what came to be the online game, "Code Fred: Survival Mode"

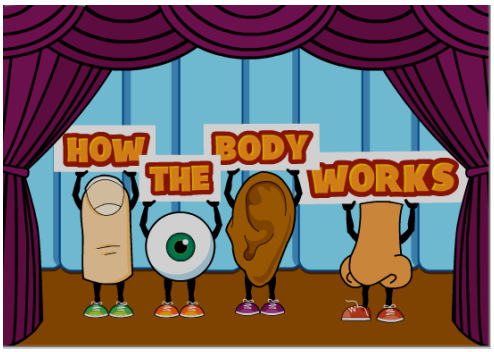


Figure 1: An example of what we did not want to make.

Goals of the game:

- To represent the body as a whole and show how body systems are interconnected and interdependent.
- To delve deeply into how individual body systems and processes work.
- To offer connections to how the user's own body works, and insight into the extraordinary processes constantly happening that go unnoticed.

Target Audience

This game would be layered enough to be interesting to teens or adults on a narrative and game play level, but with enough deep science content to also be useful as a classroom tool.

It was important to us that the experience and interaction be truly fun and compelling enough on its own that *individual* users (as opposed to teacher-led classes) would enjoy it and want to repeat play, while also accurately communicating science content that could be used in an educational context.

Game Architecture

Since we took the entire body as a subject, it was not surprising that we struggled with how to frame the content of the game. We wanted to offer users direct interaction with body parts and processes, but also to convey the larger sense of the interconnected "whole body". Our early conceptual designs fluctuated between involvement at the detail level within systems and exploring the connections between systems at the whole-body level.

Design question:

How can a massive amount of content be structured into a playable experience?

Idea 1: Macro-level exploration

Show an inside view of the whole body with all the systems (circulatory, respiratory, nervous, muscular, etc.) operating in tandem, like the gears of a clock. By hovering on zones of the body, basic information about individual systems and organs pop up. The user could toggle on or off each body system to see how different combinations of systems work together.

The problem: The user has no agency or goal; this would be pure exploration and not a game.

Idea 2: Player as juggler of the body systems

Present the whole body view of all the systems operating at once, but allow the user to control each system individually and see the effects on the other systems. Additionally, the player would have to react to different physical and emotional "episodes" that the body encounters over the course of a day and keep all the systems running smoothly: what happens when the body eats, sleeps, or is in fear? These "episodes" quickly became more and more extreme.

The Problem: manipulating meters that represent body systems was problematic. What did raising the heart meter mean, for example? Was the goal always to maintain equilibrium between the systems, and if so, what about events like running from danger

that require an abnormal physiological reaction? There was also no opportunity to engage in more granular body processes to understand how these systems operate.

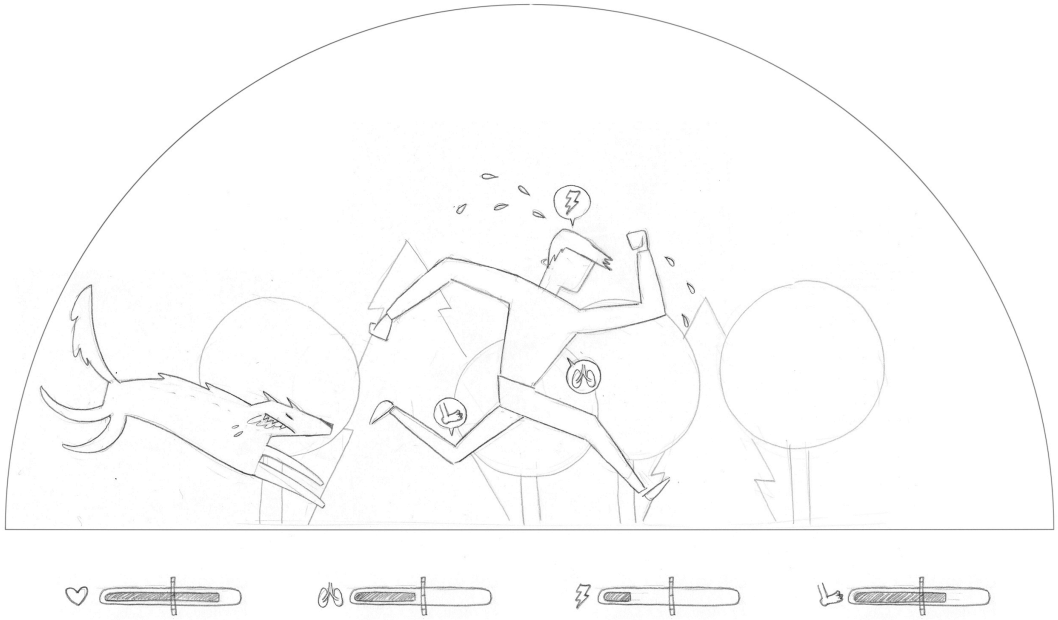


Figure 2: An early concept for the game shows meters for each body system that can be used to manipulate the body's reaction to events, such as being chased by a wolf.

Idea 3: Both macro- and micro-level gameplay

Present a character-driven narrative that connects separate mini games. These mini games allow the player to dive into the detail view and directly participate in physiological processes. Each process in a mini game will connect to the narrative and show the larger effect of that physiological process. The mini games would be based on events and processes that highlight relationships between body systems, and the totality of the games would show the body as a complex, unified whole.

Concept:

The game is based on a main character who is camping in the woods when he is suddenly chased by a ravenous wolf. This sets off a chain of events in which the player must help the character escape from a series of dangerous situations by playing mini games that each facilitate one necessary body process. Throughout the entire game, the wolf is chasing the character—if at any point the player loses a mini game, the wolf catches up and eats the character.

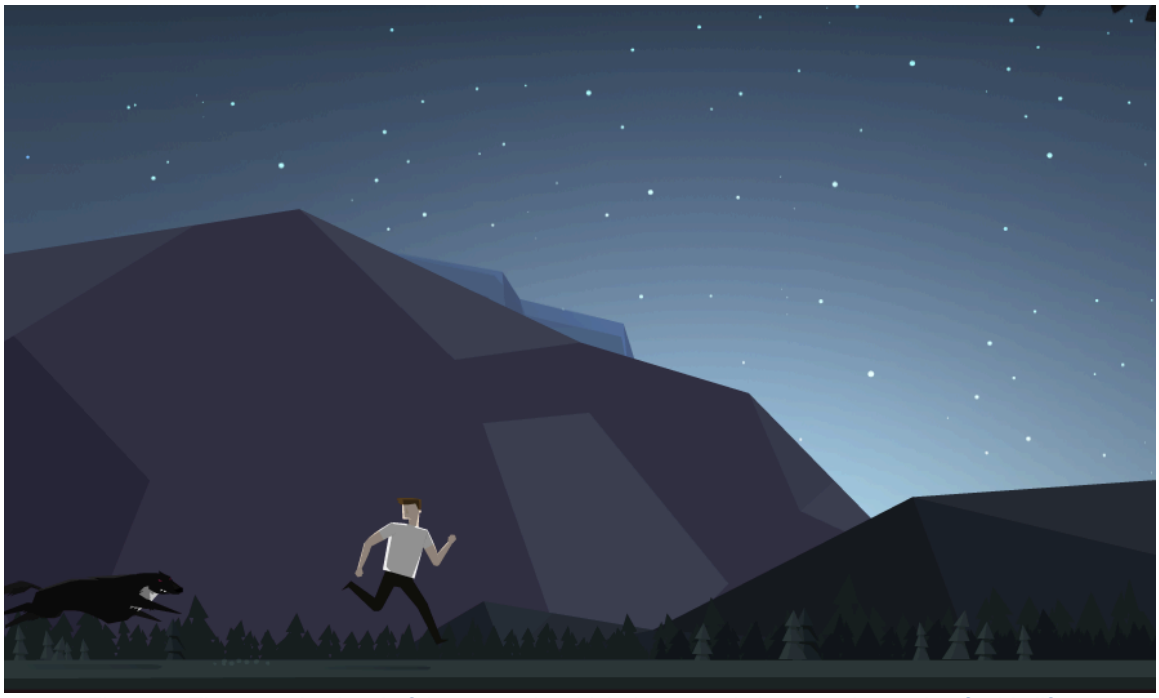


Figure 3: The narrative level of the game, in which the central character is running for his life.

We narrowed down the content of the game to four narrative scenarios that highlight connections between body systems and had the most potential for compelling gameplay: the fight or flight response, trauma, infection, and digestion. Within each of these scenarios were three mini-games that delved into a different part of that process.

Running from danger (chased by the wolf)

- Release the fight or flight response
- Raise the heart rate to circulate more oxygen
- Deliver oxygen to muscles with hemoglobin

Severe trauma (bitten by the wolf)

- Constrict broken blood vessels
- Form a clot and a scar
- Regenerate severed nerves

Infection (inhales bacteria)

- Use cilia to expel foreign bodies
- “Eat” bacteria and foreign bodies with macrophages
- Fight infection with antibodies

Starvation and Digestion (starving, then finds food)

- Metabolism (prioritize where to send the last of his energy stores)
- digestion (break down nutrients)
- Glucose (manage blood sugar levels with hormones)

Game Mechanics

Abstract interfaces and concrete mechanics

To save on development costs, we wanted to create several flexible game engines that could drive all 12 mini-games. The goal was to create game engines based on mechanics that would allow the user to "embody" and directly facilitate the physiological events. Our hypothesis was that if the *mechanics* of the game were what communicated the connections between body systems and how physiological processes work, then we would have more freedom in how we represented the events taking place in the body.

Design Question:

Can educational content be communicated through game mechanics instead of visual representation?

For example, if the goal of a game was to understand the relationship between heart rate and breath rate, could we design a completely abstract interface focused only on manipulating the two? Grasping this connection between systems was a more important learning goal than knowing exactly what the circulatory system looked like, or even all the correct vocabulary. In fact, would this game have to take place in the body at all?

The Click Mechanic

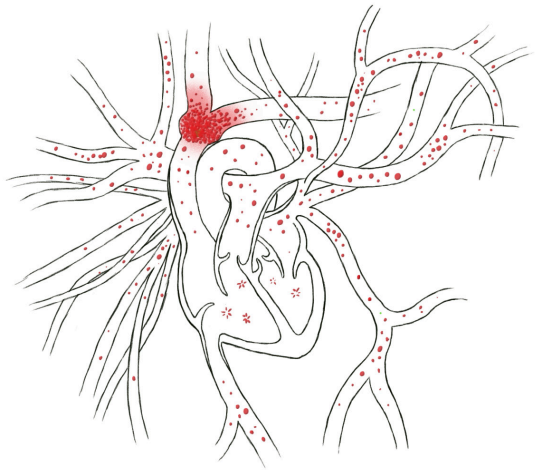


Figure 4: Initial sketch of a click mechanic game, in which the user must click quickly in different places to make something happen. In this case, they must click on the red dots to prevent platelets from sticking together and forming a blood clot in a vein.

We started with the basics: a fast mouse click game. In this game engine, one click in the game equals one action in the body—the user is directly making something happen. We experimented with this engine across a variety of games:

- Running from danger: Click to bind hemoglobin molecules with oxygen molecules in the lung, then click to release the oxygen when they reach the muscle.
- Infection: Click to “eat” bacteria with a macrophage.
- Digestion: Click to break down each nutrient as it passes through the digestive tract.

These games had the most literal user interaction, and often, the most realistic representation of the body.

The Rhythm Mechanic

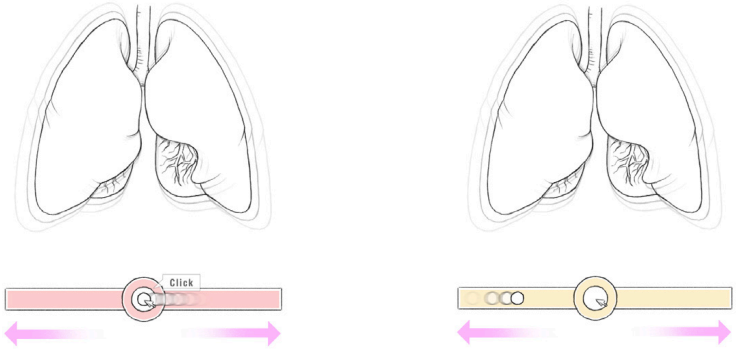


Figure 5: An early concept of the rhythm mechanic, used here to follow the breath rate by clicking the circle in the correct timing.

To take the concept of embodying physiological processes even further, we experimented with mimicking rhythms in the body as a form of interaction. The goal was to not only have the player follow an organ’s rhythm correctly, but to see the effects of that rhythm on other parts of the body. For example:

- Running from danger: raise the heart rate in the correct rhythm in order to circulate more oxygen to the muscles.
- Infection: “whip” the cilia in the throat in a coordinated rhythm so that bacteria-filled mucous can be moved upwards and coughed out.

The Connection Mechanic

The most difficult mechanic to design was one that conveyed *communication* between body systems. Often the physiological processes in these games were harder to visualize and didn’t offer good points of interaction.

The games we wanted to use this connection mechanic in were:

- Running from danger: send signals through the senses and nervous system to release adrenaline quickly.

- Clotting cascade: In response to trauma, call elements from across the body to form a blood clot.
- Digestion: balance the hormone insulin with glucose to keep the blood sugar level stable.

Instantaneous signals and responses between the senses, the nervous system, hormones, and chemical reactions were much harder to turn into games with clear goals and variables. However, these complex connections between body systems were at the heart of the overall goal of the game, and essential to building a larger concept of how the body operates as a unified system.

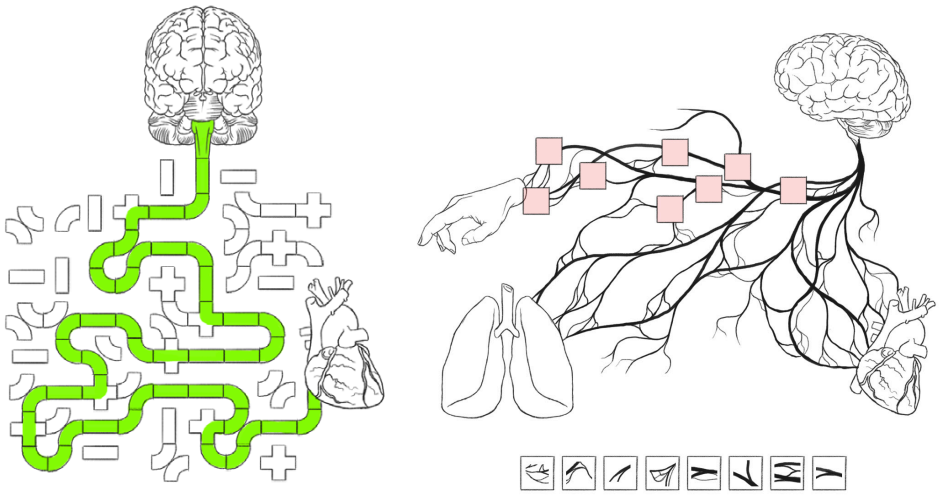


Figure 6: early thoughts on how to show the fight or flight response process.

Our early concepts for how to show these “connections” between body systems and organs took place on schematic interfaces completely divorced from realistic anatomy. While abstracting the interface made sense for such conceptual games (such as “sending” an invisible signal to affect an outcome), we quickly realized that puzzle mechanics such as in figure 5 were meaningless. The mechanic of rotating “pipes” to complete a maze had no relation to what was actually happening in the body, and getting from one point to another didn’t give the player any sense of the complexity of how the organs worked together.

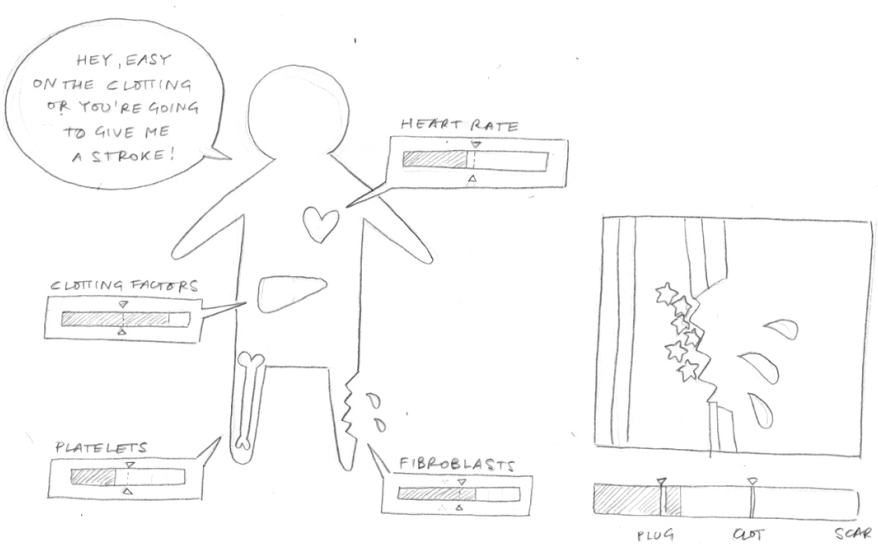
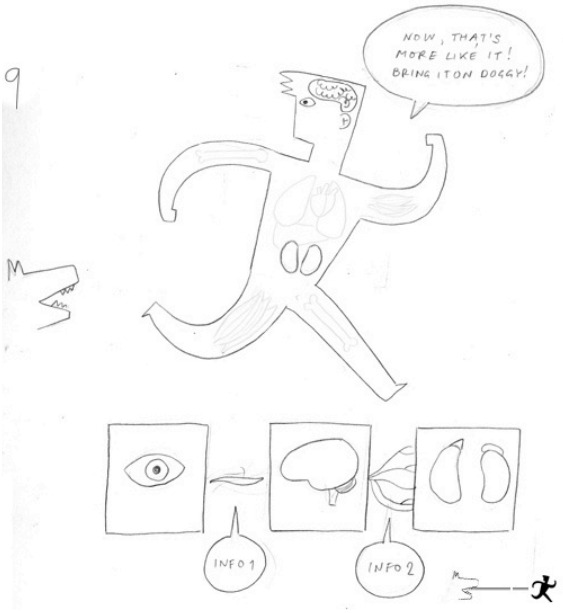


Figure 7: Another idea for the connection mechanic, used in the clotting cascade game.

Other ideas focused on manipulating variables in the body through exploratory play, such as raising meters for each of the three elements in a blood clot until the player found the right combination to stop the bleeding (Figure 6). This model was the most likely to get across the learning goal of understanding the interdependencies between body systems, but was out of scope to build for one mini game.



Finally, we focused on building a game around determining the *sequence* of events, instead of directly facilitating a process. Again, this would take place outside of the body at a conceptual level. For example, instead of directly "sending" a danger signal through the nerves, the player would choose the steps of how that information was processed in order to trigger the adrenaline release: from the eyes, to the brain, to the adrenal medulla (figure 7).

Figure 8: sketch of the connection mechanic used in the fight or flight game, in which the player chooses the sequence of organs to send information to that will trigger the fight or flight response.

Paper Prototype Testing

Interaction and Meaning

Before we invested in building twelve games based on these engines, we wanted to understand what each of these interactions conveyed to players, and what, if any, larger concepts about how the body works they communicated. Since this was not usability testing and the primary goal was to evaluate interaction, we kept the visual design and text prompts as simple as possible.

The rhythm mechanic was not feasible to test with a paper prototype, so we tested the click mechanic and the connection mechanic—examples of our most straightforward and most conceptual games.

Paper Prototype Testing goals:

- Evaluate what the mechanic communicated about the physiological event in the game and about the body as a whole
- Evaluate whether abstraction of the interface affected the understanding of events
- Evaluate what broader concepts about the body the games conveyed

Method:

- 24 youth ages 10-15 played both paper prototypes
- One facilitator managed all of the paper game pieces and prompts, while another facilitator recorded game play and asked pre- and post- surveys.
- Collected demographic information and prior knowledge questions in each content area.
- Paper prototypes were designed to replicate an online game; participants were instructed to point to an item to click on it, and game pieces were changed in response to their choices.
- Facilitators gave a very brief context both games: “This is a game about a man running from a wolf so that he doesn’t get eaten”.
- Facilitators did not give any help or verbal cues during gameplay, game instructions were read by the player as if on a computer screen.

Testing the Click Mechanic

In this game, players were prompted by in-game text to deliver oxygen to the leg muscles to help the character run from the wolf.

They were meant to “click” (by pointing to) hemoglobin molecues (white) when they were close to oxygen molecules (blue) to bind them, after which the facilitator would remove the two pieces and put down a bound hemoglobin/oxygen piece.

Players were also supposed to “click” on bound molecules that were close to the leg muscles, after which the facilitator would remove the bound piece and replace it with a hemoglobin molecule and an oxygen molecule on the muscle (to represent “delivery”).

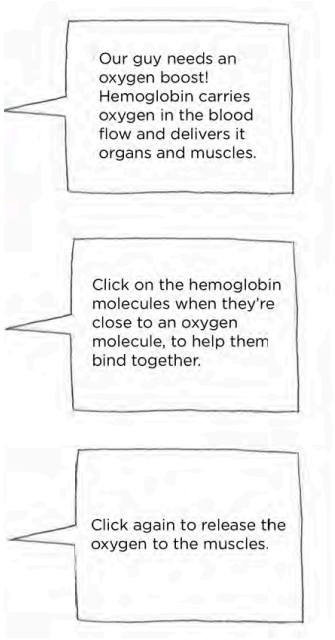


Figure 9: examples of prompts that were placed on the game interface one at a time, as if they were appearing on a computer screen.

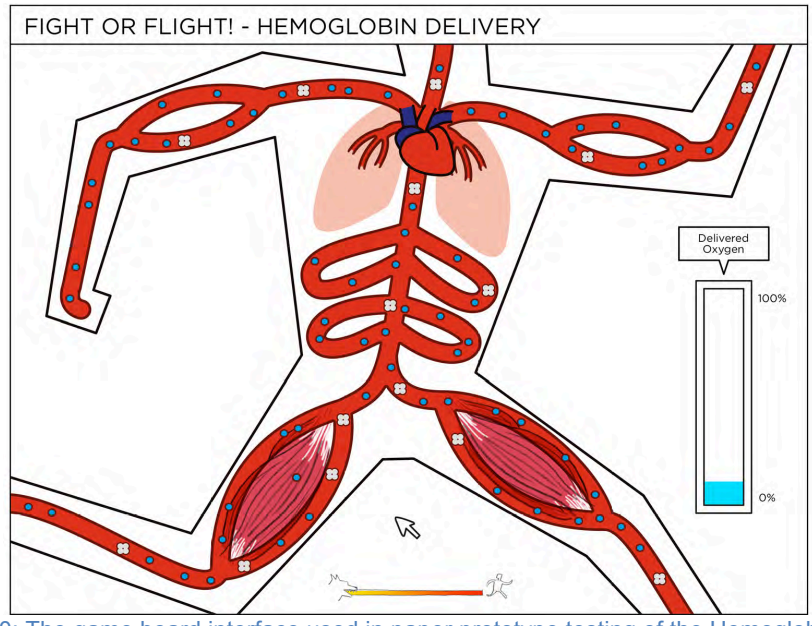


Figure 10: The game board interface used in paper prototype testing of the Hemoglobin game.

Results:

This game was very successful. The mechanic of clicking to bind and release oxygen and hemoglobin seemed to make perfect sense to players. All of the players were able to use the clicking mechanic to play the game, and could verbalize what the click represented afterwards.

Several players said that it would have been better to drag the oxygen into the muscle, or drag the molecules together to bind instead of clicking. However, the paper prototype did not show the planned animation and so didn't include the added challenge of clicking molecules as they moved quickly all over the interface, which we thought would be more challenging than a dragging mechanic.

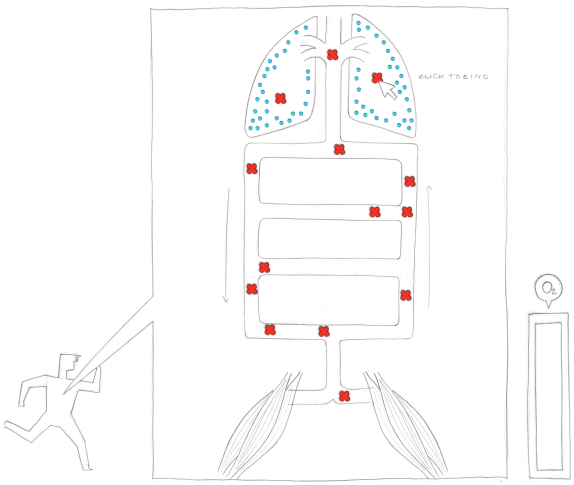
Some of the players did not realize that this was happening in the blood vessels; some thought the drawings of blood vessels on the body were ribs or intestines. Interestingly, most of those players still got the overall learning goal.

Recommendations:

- Keep the click mechanic as is. We expect that it will work equally as well in other games, and convey a straightforward, action-oriented concept of physiological processes.
- Increase the visual abstraction of this game, and potentially other games using this mechanic.

Design Changes

We suspected that the reason players were confusing blood vessels with ribs or intestines was because they were schematic, but still represented on an outline of the body. Making the vessels larger and more schematic was necessary for game play, but their placement on the chest and stomach implied that the vessels were other organs.



We revised the game interface to be even less realistic, and removed the outline of the body to further convey the maze or track-like network of connections between the lungs and the target muscles. However, this design (figure 10) still relied on the framework of the body and the general placement of organs within it. As such, the maze of vessels in the vertical space between the lungs and the legs still implied that it was the intestines or ribs.

Figure 11: an iteration of the Hemoglobin game.

Next, we completely removed the visual connection to the body in the mini game itself (figure 11). The network of vessels where the interaction took place became even more abstract and the connection between the lungs and muscles lost any realistic alignment.

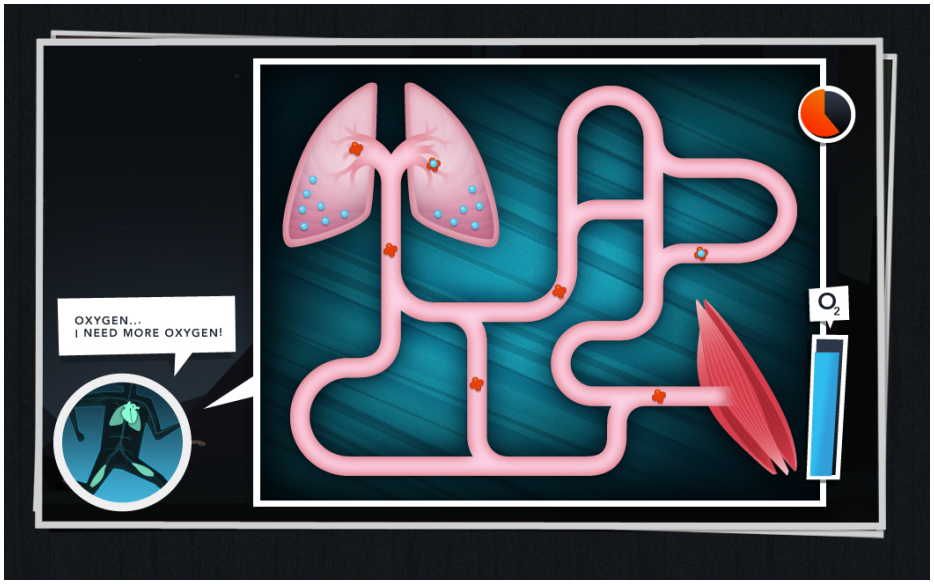


Figure 12: The final version of the Hemoglobin game, with a purely conceptual interface that is disconnected from the body. Note the "you are here" diagram in the lower left.

However, even though the interface resembled a "dream space", we still wanted users to know where this even actually occurred in the body, and be able to relate the parts in this game to the "whole body". This led to the convention of a small x-ray-like diagram of the character's body that highlighted the organs and systems involved in the mini game. We pictured this as a "you are here" map inset, relating the micro view of a street to the macro view of the city. Using this diagram across all 12 games maintained a connection to reality in the mini games, as well as the showed systems-level connections that were important to the overall goal of the game.

Testing the "connection" mechanic

In this game, players were shown text instructions to "Send a danger signal to the right organs in the correct order to release adrenaline." Originally they were supposed to "click" (by pointing) to organs on the body to "choose" them for each of the three steps, after which the facilitator would place down an organ icon in one of the numbered boxes. After several players asked to see the pieces in front of them, facilitators began laying out all the available organ icons below the game interface.

Players got immediate feedback on right and wrong choices, in the form of speech bubbles from the character reacting to their choices, and a red X over a wrong organ choice.

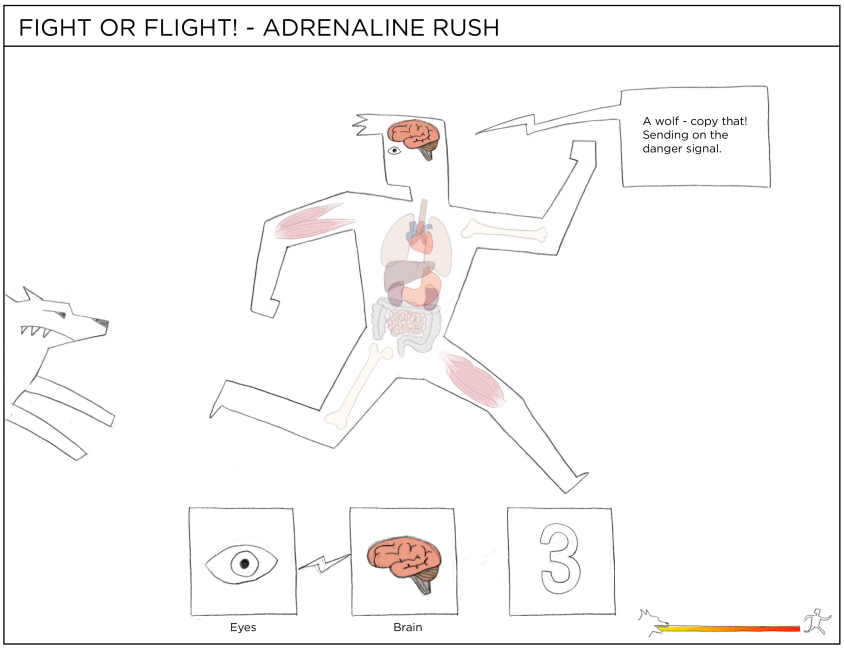


Figure 13: The game board interface used in paper prototype testing of the Fight or Flight game.

Results:

This game was not as successful. Almost every player was confused as to where to start or what they were supposed to do. There seemed to be a miscommunication about the goal of the game, which was to take in information from the environment and send it to a sequence of organs in order to *trigger* the release of adrenaline so that the character could escape the wolf. Most players assumed that they were supposed to choose the organs that adrenaline would affect *after* it was released. Using prior knowledge about the fight or flight response and the game narrative, they chose organs like muscles (to run), the heart (to raise the heart rate), and the lungs (to take in more oxygen) to help the character run faster.

Almost all participants randomly guessed organs until they got one right. This was compounded by the fact that players did not know what many of the organs were. We expected a fair amount of trial and error, and wanted to know even if players were guessing organs, whether they understood what the sequence of organs meant.

Players seemed to respond when the facilitator laid down a “connection piece” after they got two organs right. For example, if the player correctly chose the eye and the brain, the facilitator would put down the optic nerve icon between them, showing that that was how information traveled from the eye to the brain. It took seeing the physical means of connection between to organs for many players to understand that they were related in this game. This was important, since the goal of the overall game was to demonstrate the visible connections as well as invisible communications between systems.

After the game was won by choosing the correct sequence of three organs (even after trial and error through all of the options), in-game text showed the effect adrenaline on

the body and how it would help the character (such as, the pupils dilate, which helps him to see better). All of the players understood then that they had released the adrenaline, and could describe how the game and the adrenaline release would help the character escape the wolf.

Even though as they were playing the game many players did not understand that choosing organs represented the flow of information in the body, post-game surveys showed that after they saw the result of the adrenaline release, more of them understood that their choices had triggered the response. About two thirds of players could articulate the sequence that triggered the adrenaline response -- showing that they understood that what they had done was "send" the information through the body to trigger the response.

The connection mechanic, then, was not working as we intended. The action of clicking organs that would appear in slots did not communicate choosing a path and sequence for information to flow in the body. We believed that part of the problem was that the game play took place outside of the body, so it was even harder to visualize the physical paths between organs. Besides the other changes needed to the design (such as better instructions and text prompts), the game engine itself should more literally embody the physiological process.

Recommendations:

- Completely rework the mechanic to make the connections and signals between systems more explicit.
- Represent the game on the body, not outside of it.
- Limit the number of options available at each step.

Design Changes:

The adrenaline game turned into a different game with a different goal, and as a result, different mechanics. Instead of basing the game on the sequence of signaling that triggers the release of adrenaline, it became a game about facilitating the effects of adrenaline on key organs (figure 13).

Before the game begins, an animation shows the transfer of information from the senses to the brain, and to the adrenal medulla glands. It is the player's role to send the adrenaline to the target organs, and to interact with each organ in a way that relates to the change in that organ. To "activate" the adrenaline in the eye, the player must click and hold to dilate the pupil; to raise the heart rate, the player clicks the heart in the correct double-beat rhythm until the right pace is reached; to release glucose from the liver, the player clicks quickly to fill up a meter. These three types of interaction also serve as an introduction to mechanics used across all twelve mini games.

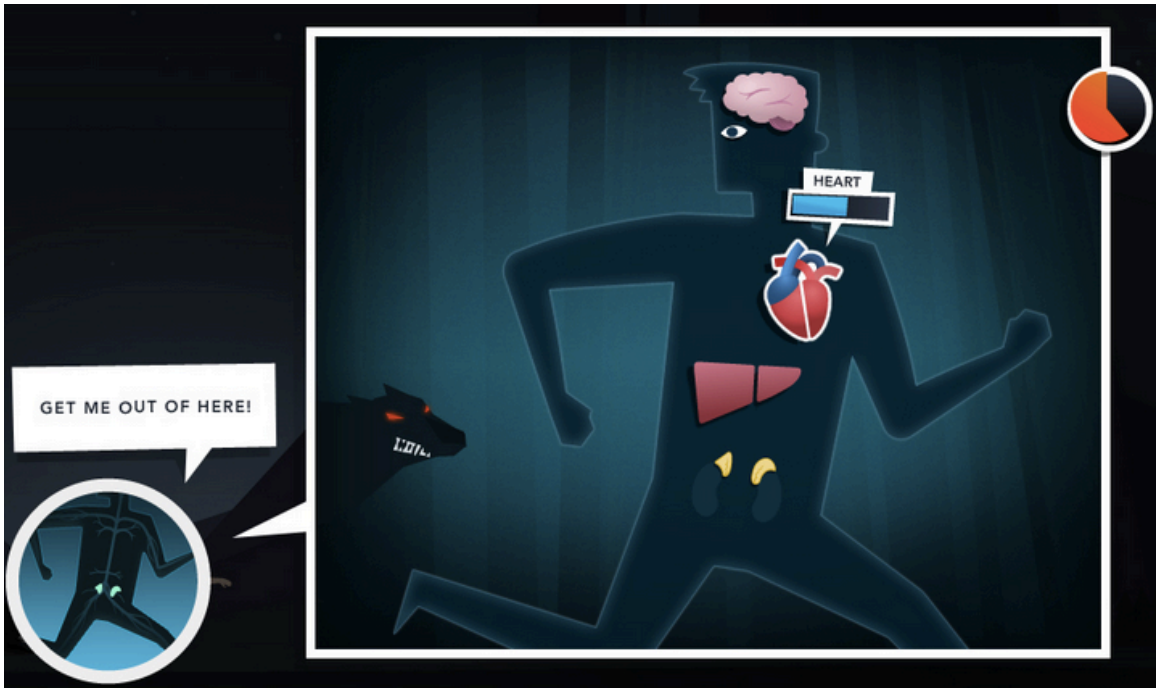


Figure 14: The last iteration of the adrenaline game.

However, this mechanic was not one that we necessarily wanted to apply to other mini games. We realized it was too hard to for one game engine to drive several of the most conceptual games, which represented very different content. The result was that we adapted the click and rhythm mechanics in different ways to show these more abstract concepts.

For example, the glucose game (figure 14) became a rhythm mechanic game and much more literal than we had originally pictured. Instead of exploratory play through manipulating hormone meters and seeing the effects, it relied on clicking the liver or pancreas in reaction to a fluctuating blood sugar level. The mechanic is centered on keeping the blood sugar in the “sweet spot”—again, the player is mimicking the effects of signals sent in the body instead of sending those signals themselves.

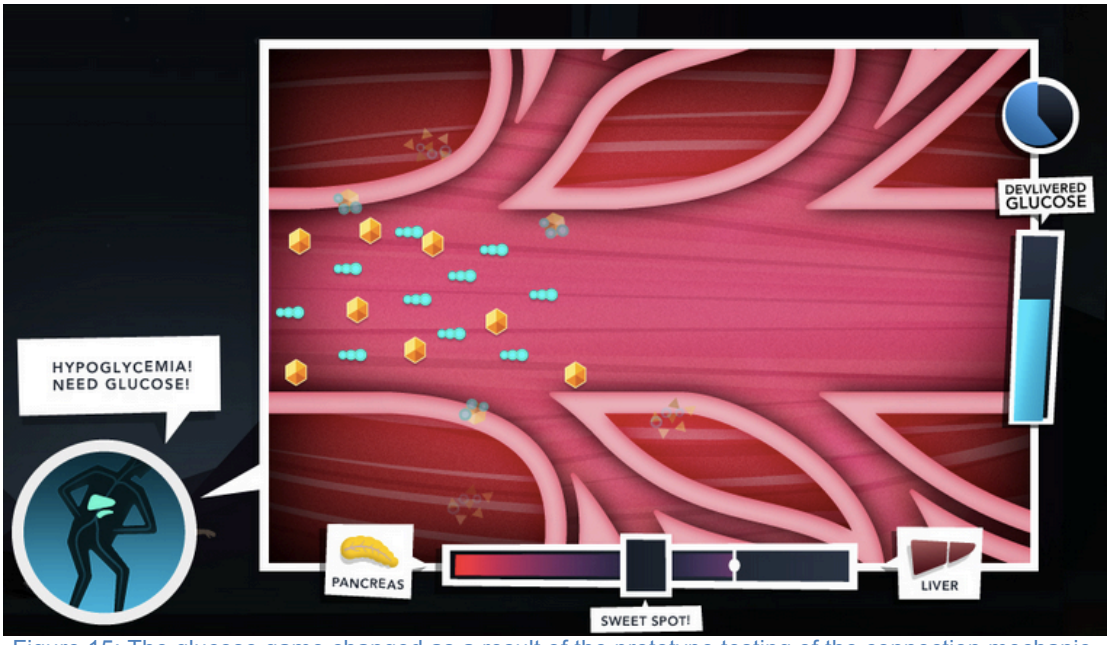


Figure 15: The glucose game changed as a result of the prototype testing of the connection mechanic.

The metabolism game, originally conceived as sending signals from organs that needed energy, also became a game about responding to signals. Players clicked on each organ to "feed" it as energy molecules floated by (figure 15). Feedback below each organ indicated when it was at a critical energy level. As the energy molecules became fewer and farther between (the character was starving), players had to prioritize which organs to feed. The learning goal was that the brain and the heart are the most critical organs to keep alive, and also use more energy than other organs.

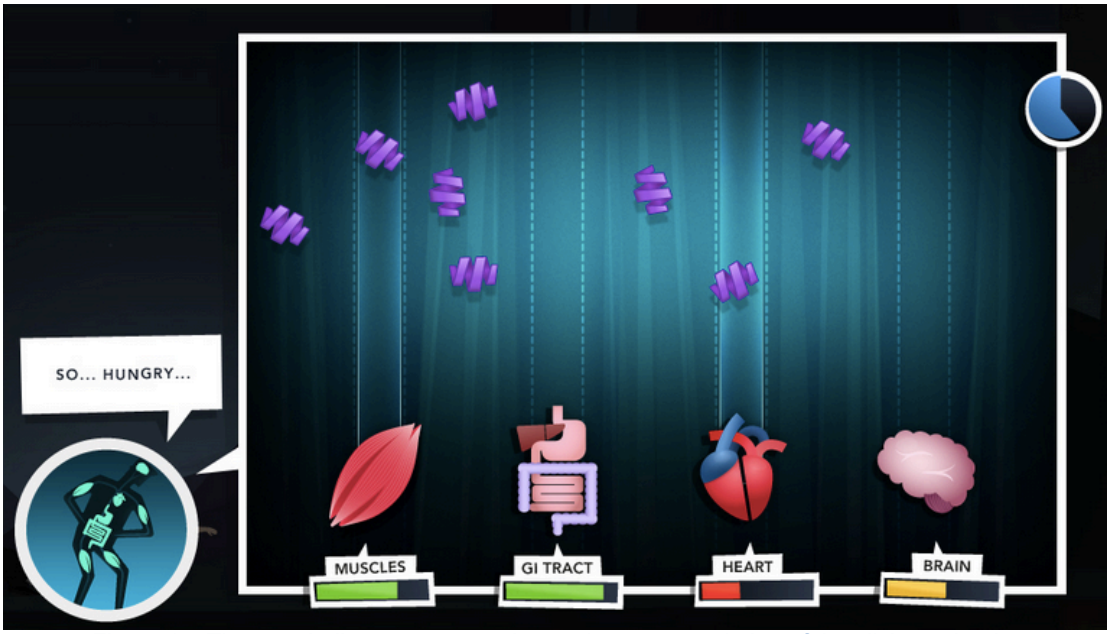


Figure 16: The metabolism game was changed to use a variation of the click mechanic.

Digital Prototype Testing

Usability and comprehension

While the paper prototype testing was done to inform the design of the mini game mechanics, we tested interactive prototypes to assess usability and comprehension. We particularly wanted to fine-tune the delivery of in-game prompts and instructions, assess whether the games were challenging enough, and evaluate whether repeat play helped players both win the games and understand the content.

Method:

- 16 youth ages 10-15 played four digital prototypes (clickable, but without full animations or design)
- two facilitators measured demographic data, prior knowledge, and took a post-game survey.
- Questions in the post game survey were largely open-ended

Results:

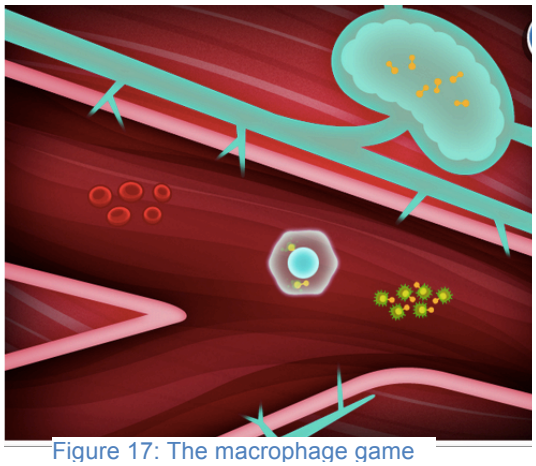


Figure 17: The macrophage game

Again, the click mechanic games were very successful. Games like the macrophage game, in which the player "eats" as many bacteria as they can by clicking on them before they multiply were very intuitive. Players frequently related this mechanic to "cleaning up", "collecting coins", and "eating bugs". However, when prompted to bring the bacteria back to the lymph node before the game ends, players thought that this represented "jail" or a "garbage can" that could be outside the body. Players overall did not notice or understand the pre-game instructions or post-game prompts that explained the lymph node identifies the bacteria and triggers the immune response.

> Quote: *"it was fun being able to move around and collect them [the bacteria] before they multiply"*

The clotting game was based on the click mechanic and focused on "building" a platelet plug, clot, then scar from elements floating in the blood. Players largely understood and enjoyed the sense of stacking and putting something together, and could verbalize that the process happened in three steps using different elements. It took most players several tries before they understood they had to click on

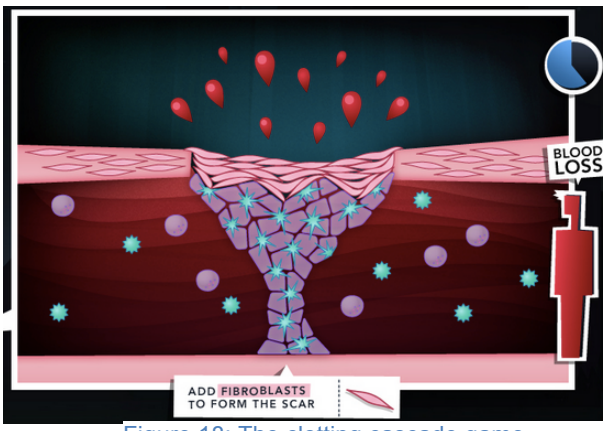


Figure 18: The clotting cascade game

elements to use them in the clot. On the second and third times, many players read the instructions and in-game prompts more closely.

> Quote*: "I thought it was a drag and drop, like most games. Once I started clicking stuff everything started working."*

The metabolism game had several design issues that interfered with usability, namely, that players did not know where to click to send energy to one of the four organs. Once they got how to play the game, though, all of them understood that they were to distribute the energy molecules to systems across the body. Most even verbalized that some organs used more energy and were more important to keep alive.

> Quote during game play*: "this game is hard…these two can wait…gotta feed the brain!"*
> Quote post-game: *"[The body is] constantly using energy, without energy it wouldn't work. Some organs use more energy than others.*

The revised adrenaline game tested much more successfully than it had in the paper prototype version. The clear feedback of filling a meter and success cues after each step greatly improved usability. Revising the game to have it take place in the body instead of outside of it also made more explicit the effects of adrenaline on organs and how those helped the character. Most players still had very little concept of the instantaneous, full body response or of communications between systems, however. Only one player could verbalize the actual learning goal of the game:

> Quote: (facilitator) *"What happened when you clicked on organs in the body?"* (player) *"I filled the meter, and once it got bigger something changed. Everything was connected, once one thing happened, then the next then the next."*

Recommendations:

- Use more in-game text prompts to call out what a player has just done successfully to reinforce content. (e.g., "platelet plug complete!")
- Reduce pre-game text instructions and increase just-in-time text prompts during game play.
- Use visual elements to show connections when they are hard to see physically in the body (e.g. arrows for hormones being sent to organs).

Conclusion

Building two stages of prototype testing into this design process was extremely useful for us. We also found it helpful to separate the testing of interaction design and other design elements; this made it easier to assess the effects of each on usability and content comprehension more clearly. Testing paper prototypes very early in the conceptual stage of the design process allowed us to establish the game mechanics the rest of the design would be based on, reinforced by actual data on what was successful and why. The changes that we made after the second round of testing were mostly front-end design and copy changes, and didn't necessitate changing any core mechanics or functionality.

For this game and the physiological and conceptual content about the body that it tries to communicate, this design process has shown us that literal mechanics that directly relate to the real actions happening in the body are the most successful in communicating how a process works. Interactions like building, collecting, mimicking a rhythm, and picking up or delivering elements allow the user to embody the physiological actions and understand relationships and processes in the body clearly. This does not mean, though, that games about the body all have to look realistic—we had a lot of success with games that took place in a totally abstract "dream space" interface, as long as the mechanics were still straightforward and embodied.

However, we did not definitively arrive at a mechanic that would achieve the original goals of communicating the complex interplay between body systems. The mechanics we designed effectively communicate how physiological processes work, and at times, how two organs or systems can work together, but they are not completely successful in showing signals and responses or interdependence. At the mini-game level, it was out of the scope to build a wholly exploratory system in which players could manipulate organs and systems and discover all the ways they are intertwined. We hope that the cumulative effect of all twelve mini-games achieves this by showing the connections between games and processes, and by inspiring awe at the complexity of the body as a unified system that the content of all twelve games represents.

MSI is planning a large-scale study to assess these learning outcomes, which will compare playing Code Fred to learning the same content in other forms.

Code Fred: Survival Mode will be available online in late October at
http://www.msichicago.org/codefred
Reports from MSI's Digital Media In Everyday Life research series are available at
msichicago.org/digitallife.