Project Narrative – Key Information, Abstract

1. Key Information for the Phase I Proposal in response to Solicitation 91990019R0011

A) Project Title:

Crescent Loom: Explorations with a Dynamic Neurobiology Simulation

B) Name of the Small Business:

Wickworks

C) DUNS:

080958229

D) Small Business Address and Phone:

719 27th St, Oakland, CA 94612
(503) 953-5476

E) Company Website URL:

`www.wick.works`

F) Typed name, title, contact information (address, phone, and email), signature, and date of signature for the Principal Investigator:

Joseph Wick Perry
Lead Developer
719 27th St, Oakland, CA 94612
503 953 5476
wick@wick.works

3 / 18 / 2019

G) Typed name, title, contact information, signature, and date of signature for a representative authorized to represent the small business concern in negotiations:

Joseph Wick Perry
Lead Developer
719 27th St, Oakland, CA 94612
503 953 5476
wick@wick.works

3 / 18 / 2019

H) List the names and professional affiliations for all key members of the project team

- Joseph Perry, Wickworks
- Emily Harris, BSCS Science Learning
- Christina D'Arcy, University of Texas at El Paso, Wickworks
- Hugh Wimberly, Wickworks
- Casey Cameron, Wickworks

I) Indicate whether the proposal is for the R&D of an entirely new product, for R&D to add new and unique components to a prototype that already exists and is functioning, or for R&D to add new and unique components to a product that is already fully developed.

O for R&D of an entirely new product where no (or limited) previous technological development work has occurred,

>>> X for R&D to add new and unique components to a prototype that already exists and is functioning, or

O for R&D to add new and unique components to a product that is already fully developed.

2. Priority

>>> X PRIORITY 1: Education Technology Products For Use by Students or Teachers (or Other Instructional Personnel) in Education Settings

O PRIORITY 2: Education Technology Products For Use by Infants, Toddlers, or Students With or At Risk for Disabilities, or Teachers (or other Instructional Personnel, Related Services Providers, or Family Members) in Early Intervention or Special Education Settings

O PRIORITY 3: Education Technology Products For Use by School Administrators in Education Settings or Early Intervention or Special Education Settings

3. Abstract

Technical Abstract

In prior research and development, Wickworks created *Crescent Loom*, an in-browser sandbox game where players tinker with the bodies and nervous systems of underwater creatures to explore the integration between muscles and the brain, ultimately illustrating how and why bodies move.

In this project, we will develop a prototype unit and educator materials that engage 7th to 12th grade students in figuring out neurobiology ideas outlined in the Next Generation Science Standards (NGSS) through scaffolded engagement with Crescent Loom. Students will observe model organisms' bodies and brains and then create creatures that can do various tasks, such as swimming and responding to various stimuli. For Phase I, we will design the first set of learning activities and educator materials about senses and reflexes. For Phase II, we will expand the product into a week-long school curriculum examining related topics in neurobiology.

We will conduct two pilot implementation and feasibility studies with high school classrooms: one preliminary and one concluding Phase I. In these, we will examine whether the prototype functions as planned, whether teachers believe the full product concept can be implemented, and whether the prototype shows potential for improving youth neuroscience content outcomes aligned with NGSS.

Summary of Commercial Potential

We plan to provide the educational module described above to schools at no charge. The commercial potential of *Crescent Loom* instead lies in its appeal as a game that is sold to students and parents after discovering the game through school. We have obtained preliminary market validation via a successful crowdfunding campaign for the prototype, early-access sales, and showcases at game conventions.

By strategically using classrooms as anchors instead of revenue sources, we will avoid the challenges of school systems as customers (inconsistent distribution channels, resource-poor) and emphasize their strengths (yearly exposure to new students, real-world assistance for players).

Project Narrative – Technical Content

1. Significance

a. Problem

In 2013, President Obama launched the BRAIN Initiative with an injection of $110 million into neuroscience research, declaring that finding a comprehensive understanding of brain function was one of the grand challenges of the 21st century. The initiative recognized that creating a dynamic understanding of brain function was an essential step "to help researchers uncover the mysteries of brain disorders, such as Alzheimer's and Parkinson's diseases, depression, and traumatic brain injury." However, these resources have not trickled down to K-12 education. The 2016 Society for Neuroscience Science Educator awardee Norbert Myslinski noted that, "In the United States, neuroscience is not a staple of high schools. Students have to go outside of the regular curriculum to really study it." (EdWeek 2018)

Contributing to this deficit is the lack of tools; neuroscience is a dynamic system-based topic that is exceedingly difficult to grasp using static presentation methods. Anatomy-focused activities (e.g. pipe-cleaner neurons) are a common stopgap for educators, but omit the dynamic network-level effects that are essential for a meaningful understanding of neurobiology. Recently, organizations such as Backyard Brains and NW Noggin have started providing engaging hands-on activities and excellent outreach efforts, but equipping a classroom or program with the hardware necessary to run neuroscience experiments still costs hundreds to thousands of dollars.

Despite evidence that digital simulations can be an effective and low-cost way to illustrate these network-level effects (Latimer et al. 2018, Wouters et al. 2013, Clark et al., 2009) and initial efforts at creating basic games for teaching neuroscience have been promising (e.g. iNeuron, Neuronify), no solution has yet been developed that realizes the potential richness of the subject by providing players with an easy-to-understand interactive neurophysiological model contextualized with a rich behavioral output. Investing in R/R&D for such a digital tool has the potential to effectively illustrate the notoriously difficult-to-visualize dynamics of neurons and prepare the next generation of neuroscientists to piece together a more complete theory of how our brains work.

b. The Product, Its Implementation, and Intended Outcomes

The Product (An Overview)

We propose using *Crescent Loom*, a game based on biologically-realistic nervous systems, to address the shortage of middle and high school digial tools that illustrate the dynamics of neurons by developing a week-long, NGSS-aligned neuroscience unit that will be available to teachers and students (grades 7-12) free of charge. In *Crescent Loom*, players build an underwater creature by assembling its bones, joints, and muscles, and then bring it to life by weaving a brain using the unique language of neurons. Neurons are simulated down to the level of ion channels, but the simulation is wrapped in a streamlined drag-and-drop interface. Crucially, players see the immediate results of their neural patterns as creatures react to modifications of their brain in real time.

In Phase I of our R/R&D effort, we will complete the prototype and related educational materials of the first session of the five-day unit, "How do our bodies move?", focused on the neurobiological basis of senses and reflexes**.** In Phase II, we will build out the other four days of the unit, add the architecture and content required for the educational and entertainment versions called for in the commercialization plan, and port the game to work on mobile devices.

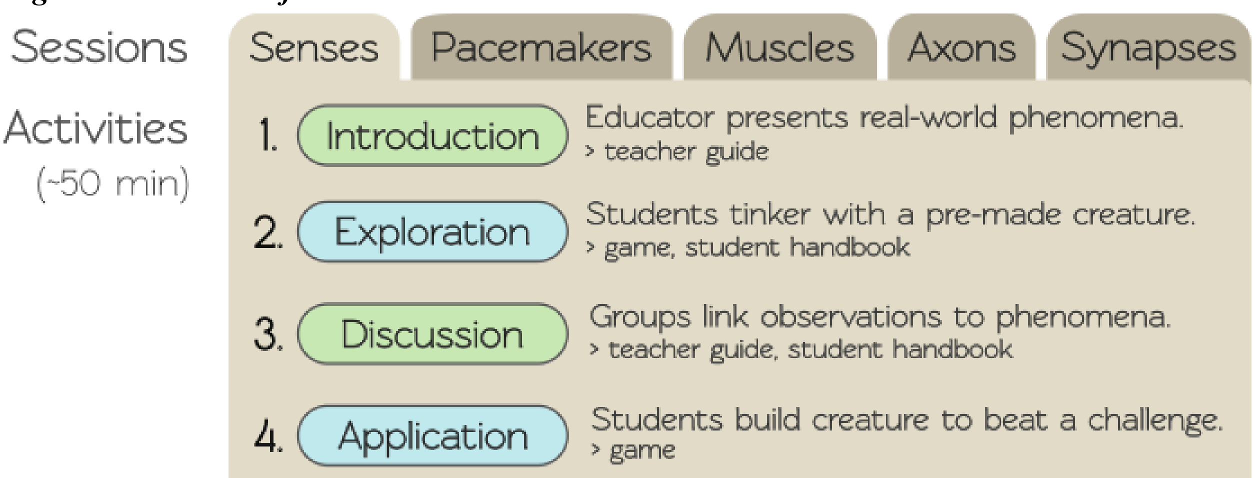
Our business plan calls for two sections of content for *Crescent Loom* to eventually be developed: one for school settings as described here, and one to be sold as a retail entertainment product. The primary source of revenue will be the latter, but the former will have an optional subscription-based product that includes a downloadable native version of the game (as opposed to the free HTML5 browser version), a teacher dashboard for monitoring student progress, and the ability to set up persistent classroom "fishbowls" of student-created creatures.

The Unit

The unit, "How do our bodies move?" integrates the social, instructive classroom environment with the engaging power of a digital experience. Each session of the unit will be directed towards figuring out a science idea by investigating a real-world phenomenon. Students explore examples of that phenomenon using *Crescent Loom*, discuss and perform sense-making, and then apply what they learned to make a creature than can overcome a challenge (Figure 1). In Phase I, we will develop the Senses & Reflexes session. The critical components to complete this session are:

1. an **educative teacher guide** to help teachers facilitate the game and subject matter
2. a **student handbook** to guide exploration of the simulation and record progress
3. **game content** for the exploration and application activities
4. **assessment items** and field tests to gauge and report product usability and feasibility

Figure 1. Structure of the "how do our bodies move?" unit.



Teacher guide, student handbook, and assessment

While game usage in classrooms has exploded in the last decade (23% of teachers used one in 2010 versus 47% in 2015; Speak Up 2015), learning games are most effective when paired with curricular and educator support (Wouters et al. 2013).

The **teacher guide** will include teacher background, a storyline, and detailed lesson plans. Teacher background materials will include content background to support teachers' learning of the subject matter, pedagogical content supports for facilitating learning using simulations, and alignment with the NGSS. In addition, it will include a storyline that describes how the unit is designed for coherence, describing the phenomena that students investigate, explicit connections between activities, and the science ideas students will learn in each lesson. Daily lesson plans for sessions will provide support for teacher facilitation, such as how to introduce the phenomenon, elicit students' prior knowledge, scaffold student engagement in the simulation, and facilitate productive sensemaking discussion. The guide will make clear rationale for design decisions to help teachers be more cognizant when they adapt the curriculum to fit their environment.

The **student handbook** will support student learning, with specific tasks and scaffolds as they engage with *Crescent Loom*. It will also include discussion prompts for small groups and meaning-making discussions, and serve as a place for students to record their thinking in process.

The completed unit will include both **formative and summative assessment**, detailed in a plan for teachers. Formative assessments will be embedded in the instructional materials, including places to look at student work and ways to attend to student ideas in small group and whole class discussion. The Application phase will serve as a summative assessment in the form of student explanations for the rationale behind their creature's design. As part of Phase II we will complete an assessment rubric that teachers can use to see if students have met desired outcomes.

Figure 2. Example investigative phenomena and science ideas

Phenomena: "Why…"	Science ideas students will figure out
...do we sometimes react without thinking?	Reflexes are direct sense-to-muscle connections
...does squeezing a wrist bend your fingers?	Muscles contract alongside bones to bend joints.
...do we keep breathing when we're asleep?	Pacemaker neurons unconsciously keep rhythms
...can't you catch a pencil dropped from the level of your hand?	Neurons are connected via axons, and there's a delay as information travels along the pathways.
...does drinking coffee make you shake?	Some drugs mimic neurotransmitters in synapses.

Experience Walk-through

Introduction: Students will consider an investigative phenomenon about one aspect of how the human body moves (Figure 2). The teacher will begin class, explaining that today they will be looking at how animals move their bodies using a video game, and present examples of the day's phenomenon (e.g. blinking when your eyes are puffed with air).

Exploratory modeling: Students break into groups of 2-3 students to explore a pre-made creature in *Crescent Loom*. To begin, they visit the website and enter a classroom code to open the game. They then have a limited amount of time to perform experiments on a video game creature by following and filling out the scaffolding in the student handbook. For example, a light source can be attached to the mouse and the creature will react to turn away if that light comes near to one of its photoreceptors. The handbook will ask them to examine the connectivity diagram of the creature's brain to explain why and to make hypotheses about what to change to have the creature instead turn towards the light. At the end of the exploration period, the teacher is able to remotely pause the student computers and enter the discussion phase.

Sensemaking discussion: After experimenting with the simulation, students will present their observations, discuss their understanding of what is happening and why, and connect it back to the real world phenomenon; for instance, how to change the creature to make it chase light-emitting food. At the end of the discussion period, the teacher will be able to remotely advance student computers to enter the application activity.

Application: Students will apply their findings to a bio-engineering challenge in *Crescent Loom* where they build a creature that can perform a task related to the investigative phenomenon, such as navigating a maze, avoiding danger, or competing in a race against creatures created by other students. Groups will be given the tools to modify neuronal connections in the creature's brain. The map will be filled key resources to complete the activity (e.g., food particles that give off light), and students will be able to implement their hypotheses from the exploration and discussion activities (e.g., hunting and eating this food). If judged by the teacher to be helpful, students who find successful solutions can peer-mentor groups still working on the activity.

Depending on the specifications gathered from consultation with the teacher over the course of the Phase I work, the application session may variably end with using a projector to show all of the student's creatures interacting once, or with a final verbal wrap-up.

Implementation

The product will be implemented in classrooms as a one-week unit, designed to supplement student progress towards the NGSS performance expectation (PE) MS-LS1-8, as described in the intended outcomes. The incorporation of the simulation will enable teachers to engage students in the practice of modeling to figure out the science ideas in neuroscience, a content area that is traditionally difficult for students to visualize.

Since the unit is meant to be integrated into existing biology curricula, sessions are intentionally modular to provide flexibility. Teachers may include individual sessions to illustrate behavior, physiology, or neurobiology as according to their needs. While we will provide a suggested order to emphasize connections across sessions, this modularity will make it feasible to incorporate the unit into current biology curricula and outreach programs.

It is challenging to develop a unit that can be used in classes ranging from 7th to 12th grade. However, initial tests of *Crescent Loom* in middle school and undergraduate classes showed promise that this subject matter and format was sufficiently flexible to be informative and engaging to both groups (see section 1.d). We expect to further refine techniques to implement the unit age-appropriately during Phase I and II R/R&D, and will include them as part of the teacher guide.

Resources

Technology: The unit requires a desktop computer or tablet for every 2-3 students to run the stand-alone simulation. *Crescent Loom* runs in-browser so is already cross-platform for desktop machines and runs smoothly on Chromebooks. Additionally, Phase II development will include a version of the game built for mobile devices. HTML5 game files will be available for educators to download and copy onto desktop machines if an internet connection for student computers is not available. These technology requirements are feasible because iPads and Chromebooks are the most prevalent computational machines currently present in U.S. educational environments, and internet connections powerful enough to download the ~40 MB game on school computers have become similarly common.

Funds: The browser-based version of the game, associated teacher guides, and student handbook files will be available at no charge. If an educator wishes to more deeply integrate the unit into their classroom, a yearly subscription will be available on the order of $1 per student per year, comparable to existing subscription-based products (e.g. CodeCombat, TypingClub).

Time: The entire unit is designed to take approximately one week of instructional time with each session lasting approximately 50 minutes, but the modularity of the unit allows teachers to modify structure as time and needs allow as described above.

Intended Outcomes

To address the lack of effective tools for illustrating the interplay of neuronal and network-level dynamics necessary for understanding neurobiology, we aim to make a curricular unit and *Crescent Loom* simulation whose use generates the two following outcomes:

- **NGSS Content:** Specific content knowledge aligned for the NGSS. For example, the Senses & Reflexes session to be developed in phase one will fulfill *NGSS DCIs LS1.D:* "Each sense receptor responds to different inputs (electromagnetic, mechanical, chemical), transmitting them as signals that travel along nerve cells to the brain. The signals are then processed in the brain, resulting in immediate behaviors or memories."
- **Motivation**: By providing behavioral feedback, using uncharged language ("weaving patterns" instead of "wiring circuits" of neurons), and immediately applying knowledge to overcome challenges, we aim to generate diverse student motivation in STEM topics.

c. Theoretical and empirical support

Three aspects of the design of the unit underly and lead to the project's intended outcomes, including: both phenomenon-based investigations and curricular/educative teacher materials leading to NGSS content, and simulation as an instructional tool leading to motivation in STEM.

Phenomenon-based investigations >> NGSS content

Each session of this unit is anchored in real world examples to engage students in a phenomenon relevant to students' lives. Students will tackle specific sub-questions that focus on different aspects of how our brains work to cause different movements. The materials will provide scaffolding for these questions, both within the *Crescent Loom* simulation and outside of it, such that students will work through a series of just-manageable challenges that push their understanding. In this way, students will not be told the science ideas: rather, they will experiment within the simulation environment and discover key ideas through experimentation and group discussion. This kind of engagement in scientific practice — including modeling, representation, and discussion — supports students in developing conceptual understanding (National Research Council 2012, Gee 2007). Discussion and collaboration is particularly essential for consolidating learning from games; a meta-analysis by Clark et al. 2014 found that "collaborative game conditions outperform single-player game conditions relative to non-game conditions".

Curricular and educative teacher materials >> NGSS content

Educative curriculum materials effectively support teachers adapt and facilitate learning experiences, leading to increased student learning gains (Davis et. al., 2017). The unit will include these to help teachers understand the design by making explicit the purpose of each move. This will allow teachers to maintain fidelity to the intent of the design while making modifications to meet the needs of their students (McNeill et. al, 2018). This is particularly important with NGSS instruction, as it presents a shift from learning about science ideas to figuring them out.

Curricular materials (i.e. the student handbook and lesson plan) provide scaffolding for the simulation. At the start of the unit, the simulation will be "targeted" with students having a few controls to help them focus on specific phenomena and interactions of interest. As they progress through the sessions, the game offers an increasing level of control. Clark et al., 2009 found that such targeted simulations "(1) minimize training time for effective use by students and teachers, (2) support effective exploration and inquiry in short periods of curricular time, (3) focus users on the specific phenomena and interactions of interest, and (4) provide high levels of flexibility for integration into existing and new curricula."

Finally, initial assessments conducted by Wickworks for *Crescent Loom* in 2017 with members of the public, high school, and undergraduate neuroscience students suggest that playing the game with light direction could lead to increased content learning. We surveyed 36 users ranging in age from 10-35+ about their experiences playing for 10-60 minutes. 74% of users agreed that *Crescent*

Loom helped them visualize neurons in new ways and 71% reported that playing the game helped them better understand how neurons behave. One college-aged participant reflected, "*Crescent Loom, by allowing the user to build an animal from the brain up, allows a much more in-depth view and understanding of how neurons actually function, in real time*."

Simulation as an instructional tool >> Motivation in STEM

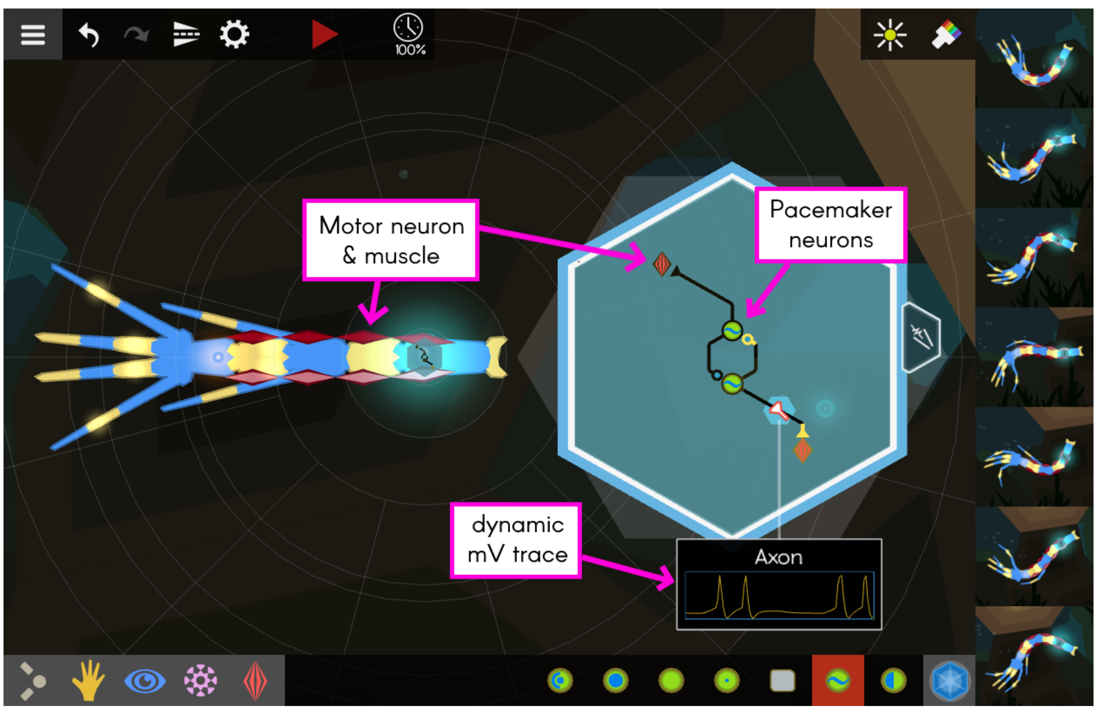
It is well-documented that games as learning experiences can result in better motivational affect compared to traditional instruction (Yang 2012, NRC, 2012). *Crescent Loom* allows students to visualize neurons in the context of a model organism, giving them immediate behavioral feedback as they explore different patterns of neural connections. However, to retain the educational benefit of the experience, it is vital that the game is paired with instructional support (Wouters et al. 2013). As such, we have retained the structure of the game, which students will enter with the intention of understanding a question and afterwards make meaning of what they experienced.

d. Related R/R&D by the project team

Description of the prototype

The proposed R/R&D will add new components to the existing *Crescent Loom* prototype, which was developed following a successful crowdfunding campaign in early 2017 on a budget of a little under $17,000. It has been showcased at a dozen game and science conventions (including Games For Change, Indiecade, and the Society for Neuroscience conference), covered by the videogame site KillScreen, and selected by the international game accelerator program Stugan as one of 15 games (out of ~500 applicants) to be developed during their 2018 summer program.

Figure 3: Annotated screenshot of the user interface and example creature.
Reciprocally-inhibited pacemaker neurons (green circles) alternate in activity to activate motor neurons (red diamonds), which contract their corresponding muscle and cause the creature to propel itself by bending back and forth, as shown in the zoetrope on the right. Action potentials and sub-threshold oscillations can be seen in the membrane potential (mV) trace.



Crescent Loom is written in the programming language Cerberus X, which transpiles to various languages depending on the target platform. Consequently, we have already ported the game to HTML5 (browser), .exe (Windows), and .app (OSX) files, and anticipate the Phase II development of a mobile build will not present major technical hurdles.

The currently-functioning features of the prototype include: biophysical simulation of neurons using an RC-circuit compartmental model including ion channels, neurotransmitters, action potentials, and passive conductance along dendrites; underwater physics and creature body parts that can be assembled by the player; a streamlined UI for building bodies and brains; sensory organs for sight, touch, and orientation; a map editor and scripting pipeline for efficient creation of level content; saving and loading creatures from an online server; a multi-creature race-course challenge; and a voiced tutorial for the game's basics.

See Figure 3 for an annotated screenshot and zoetrope of a simple creature made with the prototype, and a trailer of various creatures here: `www.youtube.com/watch?v=jzoLJBHffyE`

Prior research and results on usability and feasibility

The initial feasibility of *Crescent Loom* as an engaging product that can co-exist as both an educational and entertainment product was established during its Kickstarter campaign (detailed in commercial application, below) and following beta-tests with backers and showcases at game conventions. Additionally, we have informally field-tested *Crescent Loom* in three educational settings: an after school program for grades 6-8 (Monument Crisis Center, CA), a high school (Emerson Preparatory School, Washington, D.C.), and an undergraduate neuroscience course (Reed College, OR). These tests focused on evaluating student engagement, usability, and the grade level at which *Crescent Loom* content would be appropriate.

The lower limit for engagement was the ability to physically operate the computer; children 10 and under were happy to smash creatures into each other. Showcases with slightly older youth (ages 10-16) (e.g. at Minefaire, a Minecraft convention in San Mateo) demonstrated that youth enthusiastically and meaningfully engaged with the prototype.

At the after-school program at Monument Crisis Center for grades 6-8 (Figure 4), we observed students designing, collaborating, and iterating on creatures that successfully completing a multi-creature race course. On the upper end of the age spectrum (ages 19-25), the neural simulation was robust enough to be relevant and informative in an undergraduate setting.

Figure 4: Playtests at Monument Crisis Center (left and bottom) and Minefaire 2018 (top).

The following quotes from *Crescent Loom* game testers who completed an opt-in survey accompanying the online demo exemplify the program's potential to engage and impact student learning at different age and comprehension levels:

"Even as a biology major in a neurophysiology course, visualizing how neurons actually impact the bodies and movements of an animal can be extremely difficult. Static images really don't provide the same level of graphic visualization of how crucial timing is in a circuit, for example, or how the length constant in signal proliferation actually impacts when muscles will flex. Crescent Loom, by allowing the user to build an animal from the brain up, allows a much more in-depth view and understanding of how neurons actually function, in real time."

Student/Scientist, 19-25, 1 hour of play

"It was very fun. It didn't even feel like an education game. The thing that surprised me was that it wasn't just a game you play for fun, but actual science to teach."

Public, 13 or younger, 10 - 60 minutes of play

With the bulk of work done to make the core experience engaging, adding the proposed development of scaffolded explorations, alignment with relevant NGSS standards, and the infrastructure to allow the program to be used in classrooms are natural next steps.

e. Uniqueness of proposed product and description of similar products or typical practices

Of the existing pre-college neuroscience resources, many suffer from being too narrow or too wide in scope; they focus on the anatomy of a single neuron or the entire brain, respectively. Making models out of Play-Doh and pipe-cleaners is an effective, low-cost activity that can familiarize students with elemental shapes, but omits functional context. Students may know that an action potential travels down an axon and triggers the release of neurotransmitters, but might remain unable to describe how the axon is functionally different than a wire made of copper.

NeuroTinker and Backyard Brains have excellent physical products for teaching network-level neuroscience (Marzullo 2012). Both companies sell kits full of wires, circuits, and sensors that let students build small electronic neural networks (NeuroTinker's Neurobytes system) or interact with biological nervous system activity (Backyard Brains' cockroach and spikerbox activities). These solutions effectively demonstrate functional context, but are constrained by what can feasibly be done with hardware. Furthermore, each kit costs several hundred dollars, making them largely unavailable to resource-poor classrooms.

Digital products have the potential to be low-cost and still effectively show network-level interactions. However, most programs that have been developed thus far require an exceedingly high level of knowledge to operate (BRIAN, NEURON, Cyberslug, NEST, SimBrain, AnimatLab). Simulations built for educators (iNeuron, Neuronify) have seen promising results but tend to make drastic simplifications to neurons and lack of compelling behavioral outputs, which limits their depth of engagement and shackles them to classroom environments.

Crescent Loom avoids these shortcomings (Figure 5). It dynamically illustrating network-level neuroscience, unlike anatomy-focused crafting activities. It is available online and for free, avoiding the hardware and cost constraints of physical lab kits. Finally, it presents this material in a rich behavioral context that motivates players to learn the neurobiology as a means to an end (i.e. getting a creature to move), as opposed to for a classroom assignment.

f. Potential commercial application

The educational market is difficult to enter for new digital products: there are no strong centralized channels for distribution, and most schools are perennially short on time and funds. New

Figure 5: Cost-effectiveness analysis of tools for neuroscience education.

	Costs		Effectiveness		
	Funds	Implementation	Content format	Contextual output	Commercial product
Lecture	Free	Already standard	Abstract	No	No
Anatomy Crafts	Under $20	Already standard	Anatomy	No	No
Science Simulations	Free	Requires expertise	Dynamic	No	No
Edu Simulations	Free	Educator materials	Dynamic	No	No
Hardware Kits	$100-$1000	Educator materials	Dynamic	Yes	Yes
Crescent Loom	Free	Educator materials	Dynamic	Yes	Yes

products also face high barriers to exposing a product to teachers, getting them started, and converting them into sustainably-paying customers. However, the conservatism of school systems means that if a product does get incorporated into a curriculum, it tends to remain there and be used with a new batch of students every year.

The entertainment market potentially has more money available due to the larger number of end-users, but the market is crowded, making discoverability a big problem. Furthermore, game sales tend to peak at launch and then dramatically drop which contributes to the risky hit-based-pattern of the market. *Crescent Loom* will straddle these two environments, using the strengths of each to compensate for the weaknesses of the other (Figure 6).

Dissemination to potential end-users

Science teachers using *Crescent Loom* in their curriculum to teach neurobiology will provide the primary vehicle for dissemination to potential end users, i.e. students and their parents. We will provide *Crescent Loom*, its associated curricular materials, and educator training for free to schools (or an optional small subscription (described in section 1b) to minimize the cost-of-entry into schools, with the aim of engaging new students with the game every year.

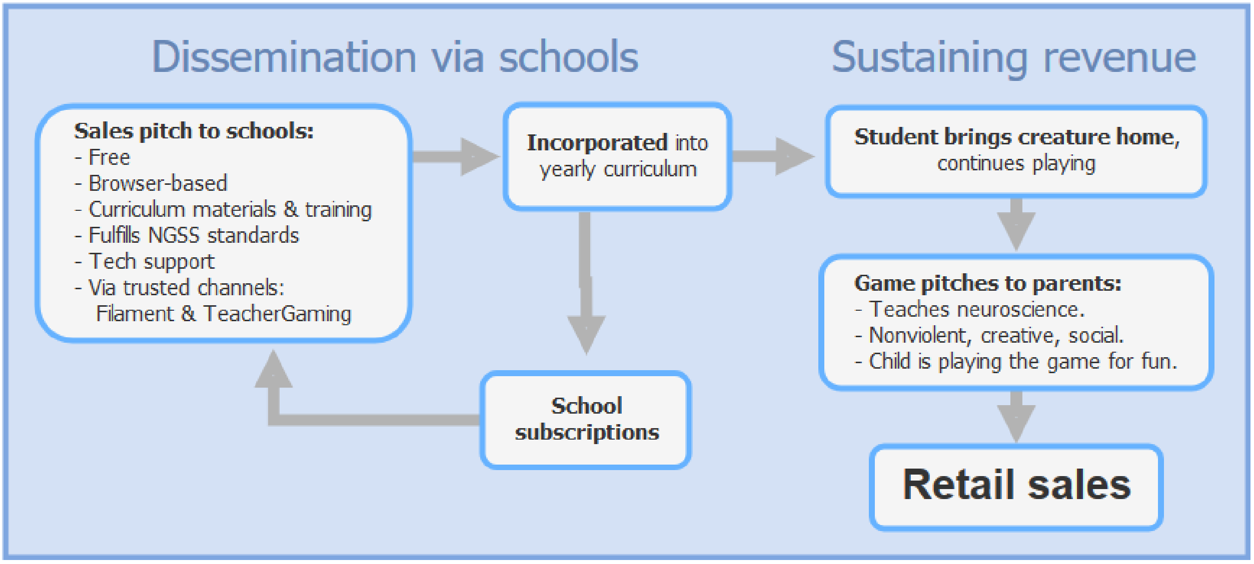
To expose and help with distribution to schools, we will primarily look to existing educational-game channels and sales teams. Both Filament Games and TeacherGaming have indicated that once *Crescent Loom* is developed and meets the learning outcomes described in this proposal, they would be interested in including it in their store and subscription service, respectively (Appendix I). Additionally, we plan to reach "pioneer" teachers by showcasing at educational technology meetings (e.g. the ISTE, FET, and TCEA conferences).

Revenue strategies to sustain the product over time

The conclusion of the learning module involves students creating their own creatures and saving them online. Students who continue playing the free browser version at home will be given the option and to upgrade to the retail entertainment version, providing a yearly stream of exposure and sales. Depending on the results of our R/R&D, we expect it to retail between $20 and $40, similar to the existing science game/simulations *Universe Sandbox*[2] and *Kerbal Space Program*.

This plan depends on *Crescent Loom* being inherently motivating enough for a student to bring it home and continue playing, a claim that many educational games make but only a fraction fulfill. However, the technical prototype of *Crescent Loom* has already generated preliminary validation that it is inherently appealing enough to make the jump from schools to homes via its crowdfunding campaign on Kickstarter (a mix of 431 students, scientists, parents, and the general public pledged a total of $16,929 in March 2017) and its success in attracting youth players and pre-orders at gaming conventions (e.g. Minefaire, OMSI mini maker faire).

Figure 6: Business model for dissemination and sustaining revenue.



2. Phase I Technical Objectives

a. Phase I R/R&D objectives

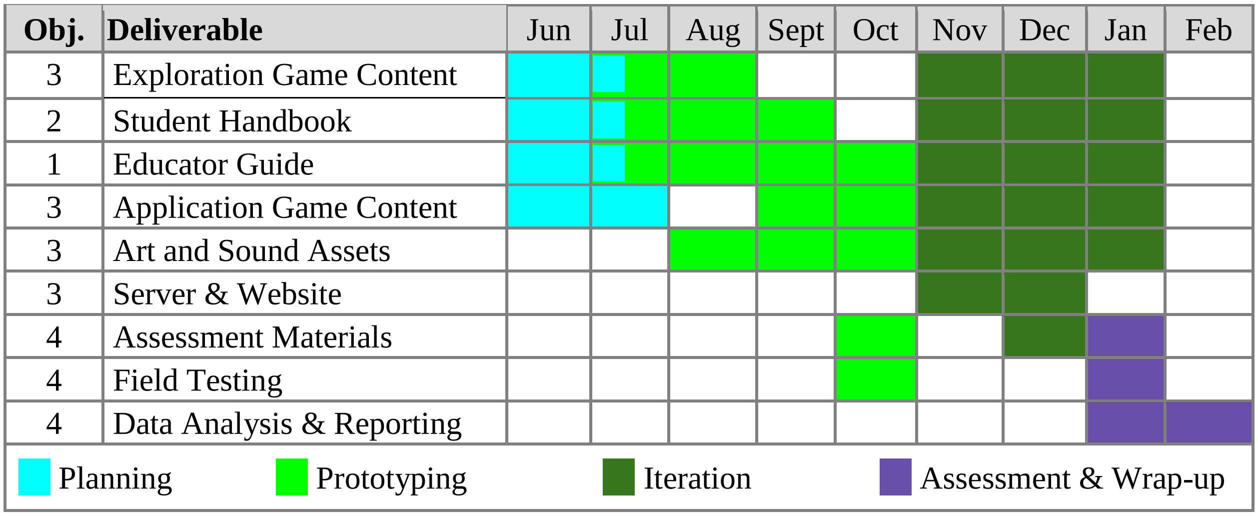
The R/R&D objectives for Phase I will develop the following four critical components, aligned with the critical components described above: an Educator's Guide, Student Handbook, game content, and usability and feasibility assessment.

- **Objective 1:** Produce a Educator's Guide for distribution to teachers.
  - Develop a rough storyline for the entire planned unit
  - Write content for leading each activity in the session.
  - Create background to support teachers' learning of the subject matter
  - Develop pedagogical content supports for facilitating learning using simulations
  - Build a website where educators can easily access these materials and the game
- **Objective 2:** Produce a Student Handbook for distribution to students.
  - Write questions to scaffold the Exploration activity
  - Develop prompts for the Discussion activity and meaning-making
  - Develop assessment activities, including bug reports, an enjoyment scale, material comfort and interest, and open-ended suggestions
- **Objective 3:** Design and build *Crescent Loom* content for the Senses and Reflexes session.
  - Design scaffolding for the Exploration activity, including a creature that reacts to stimuli provided by the UI
  - Develop a challenge for the Application activity, including hazards that students must design their creature to avoid
  - Design and incorporate art and sound assets
  - Develop server architecture and interface for teacher control of play sessions
- **Objective 4:** Analyze product usability and feasibility through field testing and data analysis.
  - Conduct field tests: preliminary after school visit and final classroom assessment
  - Design and launch follow-up survey with demographic information
  - Conduct data analysis and write final report

b. Project timeline

All project activities will be completed in the eight-month grant period, as shown in Figure 7 (note the Objective associated with each item) and described in the Work Plan below.

Figure 7: Crescent Loom Phase I timeline



3. Phase I work plan

a. Development of the prototype

All work, except the usability and feasibility study, will take place at the Wickworks co-working space in Oakland, CA, with project partners contributing to the project remotely. The usability and feasibility study will take place at Emerson Preparatory High School in Washington, D.C. The entire project team staff will meet regularly via Slack and the curriculum and development teams will meet regularly in-person in Oakland.

Planning (June-July 2019) Objectives 1, 2, and 3.

The curriculum and development teams will begin the initial game and storyline and lesson design documents immediately, starting with designing and writing the in-game and handbook content for the scaffolded exploration and application phases. These will be designed in consultation with the advisory board for expertise from the edu-game industry and neuroscience outreach programs. Once designs for the content of the exploration activity, the application activity, and the overall storyline for the unit are finished, we will move to the prototyping phase.

Prototyping (July-October 2019) Objectives 1, 2, 3, and 4.

The curriculum and development teams will start prototyping the in-game and student handbook content for the Exploration section using *Crescent Loom*'s existing level-creation tools. This will involve elaborating on the visual sensory system to detect various types of objects and intensities of light, developing a creature for students to interact with using a wireframe UI, and writing scaffolding for the student handbook.

Once the Exploration section is prototyped, they will move to working on the educator guide (storyline, supports for leading the Introduction and Discussion sections, and subject matter background) and Application in-game content. This will involve designing body parts and neurons for players to use in avoiding level hazards. Additionally, the art and audio teams will create concept assets during this phase, guided by specifications from the planning phase.

The milestone at this phase will be conducting an initial informal field test of the exploration and challenge activities at Corbett High School (Corbett, OR), to shape iteration of the game design and guide the final assessment methodologies. The development, curriculum, and evaluation teams will be on-site to observe it being run, take notes, and help facilitate the activities. The evaluation team will support this by adding sections in the student handbook for the usability and feasibility assessment and a space for students to report bugs.

Iteration (November 2019-January 2020) Objectives 1, 2, 3, and 4.

Guided by results from the internal field test, the curriculum and development teams will finalize the scaffolding for in-game activities and student handbooks. In collaboration with teachers from Corbett and Emerson high schools, we will also finalize the educator guide, including the unit storyline, content background, and a guide for the introductory and discussion phases of the activity.

With the draft of the educator guide and student handbook complete, the network team will build a website that hosts this pedagogical content and integrate it with the server architecture that supports teacher control of a play session (i.e. being able to start, stop, and advance through activities). The development team will also work with the art and audio teams to implement their final assets. Near the end of the iteration phase, the evaluation team will finalize the assessment materials in preparation for the classroom field test by writing the demographic survey and modifying the student handbook assessment sections using results from the initial field test.

Assessment & Wrap-up (January-February, 2020) Objective 4.

The final usability and feasibility test will take place near the end of Phase I in late January. We will give the completed "How do our bodies move?" prototype unit to the Emerson Preparatory School biology teacher. The development, curriculum, and evaluation teams will be on-site to observe it being run and help facilitate the activities.

The development and evaluation teams will spend the final weeks of the project processing and writing up the data from the field test and making the summary video for the final report.

b. Research on usability of the prototype and initial feasibility

At the end of Phase I, we will test the usability and initial feasibility of the product concept for *Crescent Loom* in a classroom setting. Corbett High School and Emerson Preparatory School have agreed to participate for the preliminary and final field tests, respectively (Appendix B). Overall, about 40 students in grades 9-12 will participate in testing and evaluation.

Using a mixed-methods approach to assess curricular activities, a final summative evaluation of overall product function, curriculum integration, and user feedback will be provided. Briefly, program usability will be addressed through “bug report” evaluation forms issued to participants to be completed on an as-needed basis during the session. Evaluation forms will provide clear instructions and descriptive scales of severity (adapted from Benson et al., 2002) to describe the problem along with frequency of occurrence. Data will inform developers of the elements of the game that are technically faulty or broadly disruptive to the gameplay experience.

After completing the curricular activities, an electronic exit survey will be issued to participants, consisting of a 1) a demographic component, 2) scaled attitudinal questions modeled after the Core Elements of the Gaming Experience Questionnaire (CEGEQ) (Calvillo-Gámez et al., 2010); 3) scaled attitudinal questions regarding participant attitudes toward the game in an educational context (usefulness and learning opportunity constructs modeled after Bourgonjon et al., 2009); and 4) open-ended prompts addressing constructs for game and curriculum elements enjoyed, elements disliked, requested additions, and requested changes indexed for language clarity (tooltips, instructions), ambient assets (visual, sound), user interface (intuition), activity design (logistics, timing, and relevance). Interrater reliability among coders will be assessed.

Descriptive statistics of the population demography will be provided. Program functionality feedback will be indexed by the type of error encountered and represented by severity of the problem versus the aggregated number of incidents of occurrence after controlling for effect of computer stations. Scaled survey data will be reported (M, SD) for individual questions categorized by construct. Data will be analyzed using a series of Analysis of Covariance (ANCOVA) and Multivariate Analysis of Covariance (MANCOVA) procedures, controlling for student demographics where appropriate. Data for open-ended responses will be categorized by index and construct, reported by % occurrence with exemplar quotes provided.

Taken together, this body of information will 1) identify experiential factors which may detract from the utility of *Crescent Loom* as an instructional tool; 2) assess the degree to which student experience with technology and biology predicates perceived value and enjoyment of the game in the context of a curriculum activity; and 3) inform Phase II curriculum design and game feature adjustments required to serve the population inclusively and engagingly.

c. Potential problems

Our design is based on evidence that learning games are most effective when combined with traditional teaching methods; presentations by content experts, peer discussions, and physical materials. Rather than attempting to orientate players via purely in-game material such as pop-ups and tutorials, we are taking the experimental approach of scaffolding via a physical student handbook. Since there are not many examples of this method, we expect to have to develop innovative methods to intertwine digital and physical materials. We will look closely at existing curricula to see how they combine lab notebooks and physical experiments, and examples of entertainment games that use physical instructions (e.g. *Keep Talking and Nobody Explodes*).

While we have already conducted in-house and limited classroom performance tests, it is common to run into some number of compatibility issues when taking a digital product into the field. By running a preliminary field test partway through Phase I and being physically present to observe field tests, take notes, and provide technical support, we expect that any such issues will not be catastrophic and that we will be able to log and fix them during the iteration phase.

Finally, there is always the question of whether classroom activities (be they physical or digital) will ultimately translate to student content knowledge. While we plan on formally investigating this in Phase II, we will lay the groundwork for assessing knowledge acquisition in Phase I with student's ability to connect game topics to the real-world phenomena during the discussion section via verbal participation and the records kept in the student handbook.

4. Project Team – Biographical Summaries

Joseph Wick Perry (.8 FTE), Founder, Lead Developer, and Principal Investigator, will lead development of game content and coordinate operations. He has a BA in Biology from Reed College with a thesis on mapping connectivity and electrophysiological properties of neurons within the vocal circuit of *Xenopus laevis.* While working to publish his research, he developed a game for psychology classes to measure behavioral variability, founded Wickworks, and led the release of its first commercial game: *Starship Rubicon*. He honed his technical skills working as an engineer in San Francisco and volunteering at educational nature and coding camps for youth. His experiences have given him the multidisciplinary background needed for leading this project, including programming, game design and development, project management, and neurobiology.

Dr. Emily Harris (.35 FTE), Co-Principal Investigator, will serve as a contractor on the project, leading the development of instructional materials. Dr. Harris is a Research Scientist at BSCS Science Learning, a 501(c)3 nonprofit research and development organization in research-based science education reform. She brings expertise in phenomenon-based science learning and NGSS instructional materials development. She currently leads unit development for OpenSciEd and works on the GLOBE instructional materials design team, both of which incorporate simulations as instructional tools for secondary students. She holds a Ph.D. in Science and Agricultural Education from the University of California at Davis.

Dr. Christina D'Arcy (.06 FTE), Project Evaluator, will implement the research plan, and oversee data collection and data analysis services for Phase I testing. Dr. D'Arcy is engaged in science education research focused on authentic research experiences and active learning in the STEM fields. In recent years, she co-developed and evaluated outcomes for a novice undergraduate research-based course in high-resolution neuroanatomical mapping; designed and assessed active learning modules for an undergraduate SCALE-UP course in fundamental research skills; and provided program evaluation for the inaugural meeting of the Ethics Network for Course-based Opportunities in Undergraduate Research (ENCOUR) network.

Hugh Wimberly (.06 FTE), Systems Engineer, will implement the network architecture allowing Crescent Loom creations to be shared and distributed. He has been working in scientific and large-scale computing since 2003, has worked on nuclear particle models at INL, distributed databases at Google, and currently as a consultant specializing in high-volume data engineering problems.

Casey Cameron (.08 FTE), Sound Designer, will create music and a consistent audio aesthetic for appropriate for classroom environments for *Crescent Loom*. Mr. Cameron has a BA in Music from Sonoma State University, and 11 years of experience composing music, sound, and voiceover for games and film ranging from indie to triple-A, including work on Civilization V, Spec Ops: the Line, and Bioshock 2.

In addition to these key personnel, we will also work with two advisory board members and an external creative consultant:

Erin Hoffman is an author and video game design veteran. She worked as Game Design Lead at the Institute of Play's GlassLab, an initiative to establish integrated formative assessment educational games. Her video game credits (*SimCityEDU, Mars Generation One: Argubot Academy*, and *PuzzleSmash: Book of Secrets)* have won multiple awards, including the 2014 Common Sense Media ON for Learning award, and have been played by millions of kids and adults worldwide. Erin will provide expertise on the design and commercialization of education technology products.

Eric Chudler, Ph.D. is a Research Associate Professor and Executive Director of the Center for Neurotechnology at the University of Washington. He is a "basic researcher" performing experiments on how the nervous system works and how Parkinson's disease affects the brain. His books include *Brain Lab for Kids*, *Brain Bytes: Quick Answers to Quirky Questions About the Brain*, and *Inside Your Brain*, and advises the UW Neuroscience Community Outreach group. Dr. Chudler will provide expertise in neuroscience and its instruction.

Stephanie Stutz will serve as Creative Director to develop visual designs and art assets. Ms. Stutz has a BA in Scientific Illustration from Zurich University of the Arts and now works as a game illustrator based in Switzerland. In addition to freelancing, she works at Stray Fawn Studio, and the award-winning digital agency Dreipol. Her salary will not be covered by grant funds.

5. Resources

All equipment required for the technical development of *Crescent Loom*, including computers and software, was obtained during development of the prototype or is owned by employees. All employees work and meet remotely from home offices or at co-working spaces.

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