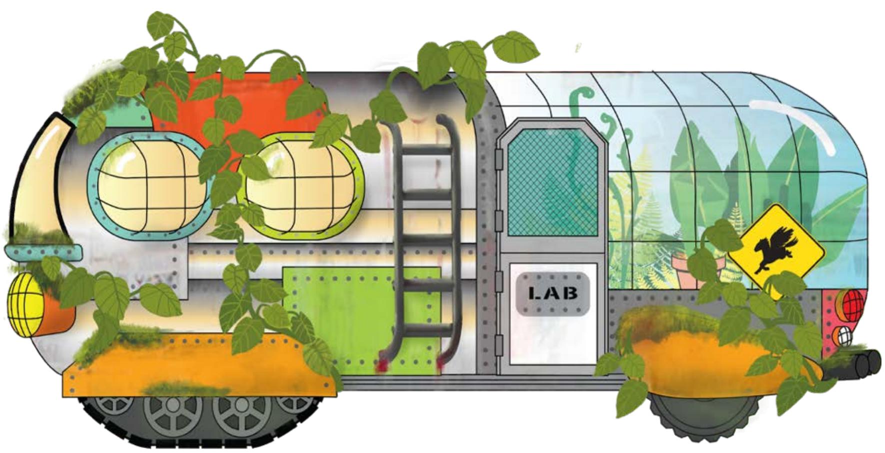
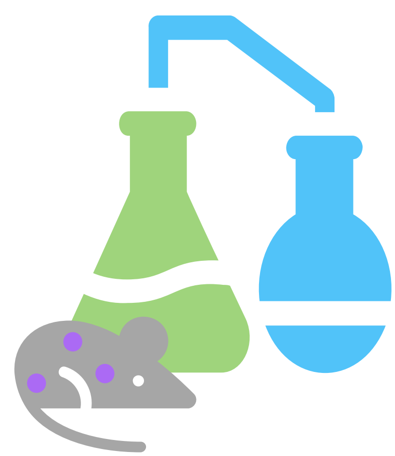
VENOMventure | aVENENOtura

2024 Summative Report



Rockman et al Cooperative
Research & Evaluation



Credits

The summative evaluation of VENOMventure was conducted by Rockman et al Cooperative, Inc (REA) under the guidance of research lead Claire Quimby, and in partnership with Dr. Lisa White, Dr. Anna Thanukos and Dr. Teresa MacDonald, project PIs. Jaime Flores (REA) contributed to the summative research design and instrument development. REA data collection support was provided by Alex Gurn, Jaime Flores, Kara Fedje, and Maggie Deagon. REA analysis support was provided by Julia Li and Kristin Bass.

We would like to extend a huge thanks to the partnering staff at Berkeley Public Library, Stanislaus County Library, California Academy of Sciences, University of Kansas Museum of Natural History, and Independence Public Library who jumped over all the hurdles of hosting the escape game and helping us to collect survey data with their guests and visitors. Without your efforts, this experience wouldn't be possible for players and the research in this report would not exist.

The VENOMventure project is supported by a Science Education Partnership Award from the National Institute of General Medical Sciences (part of the National Institute of Health). Any opinions, findings, conclusions, or recommendations expressed in this report are those of the research team and do not necessarily reflect the views of the National Institute of Health.

Table of Contents

Executive Summary

VENOMventure | aVENENOtura is an educational escape game designed by researchers at the University of Kansas Natural History Museum and the University of California Museum of Paleontology under a Science Education Partnership Award from the National Institutes of Health. The game incorporates evolutionary trees into an engaging storyline and series of puzzles designed for children ages 9-13 and their families. The goal of this educational escape game is to improve players' understanding of evolutionary trees while also boosting their interest in biomedical science and careers, all in a fun and immersive game experience.

VENOMventure was first revealed to the public in its final form in spring 2023 and traveled to four different libraries and museums between June and September 2023. The project leads partnered with Rockman et al Cooperative (REA), an independent education research and evaluation firm, to conduct a summative evaluation of the escape game and investigate whether it succeeded in advancing players' understanding of evolutionary trees and increasing their interest in related STEM topics and careers. REA researchers, supported by staff at each of the host sites, collected matched pre/post surveys from a total of 446 individuals. These surveys included a knowledge quiz as well as attitudinal items. REA researchers also conducted observations and post-game interviews with a subset of groups at each site.

Findings from the summative evaluation show that VENOMventure does support learning about phylogenetic trees. Game players were observed explaining tree concepts to one another and using key vocabulary terms as they interpreted the diagrams and solved puzzles. Participants' surveys also show a significant improvement in their tree reading skills from pre to post-test. Players scored roughly one item better (a 20% improvement) on the post than the pre on a five-item quiz. This finding held up for both the target age group (children ages 9-13) as well as younger children, and older children and adults. Participants' knowledge quiz scores dropped slightly on a follow-up survey administered one month after the event, but still remained significantly higher than their pre-game scores. Participants also improved on each individual item of the knowledge quiz, demonstrating growth across a range of concepts relating to evolutionary tree reading. The summative evaluation also examined several other factors to see if they may have an influence on players' learning, and found that group size (number of players) did not have a significant effect on individuals' quiz scores, nor did players' previous experience with escape rooms. The balance of child versus adult-driven puzzle solving, however, *was* found to be statistically correlated with learning outcomes. Adult-driven groups showed less learning than groups that displayed a balance of adult- and child-driven puzzle solving, and less than those that were mostly child-driven.

Observations, survey data, and interviews with participants all demonstrated that the game was highly engaging to players. Participants reported thoroughly enjoying the experience and looking forward to playing other games with

A family collaborates on a puzzle

science puzzles in the future. Despite starting with a lower level of familiarity and understanding of evolutionary trees, even younger players jumped in to solving the puzzles. Older players also joined in, and groups were observed to take very collaborative approaches to tackling the game's challenges. The game also was successful in piquing participants' science interest and sense of self-efficacy. Overall, 91% of adults and 71% of children agreed that VENOMventure made them more interested in topics that are part of science or medicine, and their confidence in their tree-reading skills showed significant improvement from pre to post. Furthermore, seventy-eight percent of respondents to the follow-up survey reported talking about the game in the weeks that followed, and two-thirds of these respondents said they specifically talked about the science concepts in the game.

A group playing the Tree Twisssssster warm-up activity

Overall, VENOMventure has proven to be a successful in engaging participants of all ages in a playful and educational STEM experience and in improving their ability to successfully read evolutionary trees. The summative evaluation of the game has also raised many interesting questions for future investigations, such as how child/adult dynamics influence learning in a gamified setting, what learning might look like for groups consisting of only children, and if there is an optimal group size for an educational escape room. As VENOMventure travels to additional sites in 2024, we will also be collecting information on the logistical details of hosting a pop-up escape room at a variety of venues, so that more institutions can have the opportunity to share this rich learning experience with a wide range of audiences.

Introduction

VENOMventure | aVENENOtura is a fun, fast-paced, and family-friendly escape game created by researchers from the University of California, Berkeley (UCB) and University of Kansas (KU) under a National Institutes of Health Science Education Partnership Award. Longtime collaborators Dr. Teresa MacDonald (KU) and Dr. Anna Thanukos (UCB) were searching for a new and engaging way to teach evolutionary relationships to general public audiences – an enterprise that both researchers have worked at for years through their roles at the UCB Museum of Paleontology and the University of Kansas Natural History Museum. Their shared love of escape rooms and puzzles soon grew into a new project idea – could an escape game be a good way to teach families how to read phylogenetic trees?

A family celebrates after completing VENOMventure together

Armed with an abundance of creativity and supported by an advisory team of evolutionary scientists and game designers, Drs. Thanukos and MacDonald sketched out the idea for VENOMventure - an escape game with a fantastical storyline where players have to find a cure for an itchy outbreak caused by venomous plants. To successfully create the antivenom, players must reason their way through a series of puzzles that teach the principles of evolutionary tree reading, discerning how the branching arms of a tree represent relationships between ancestors and descendants, and the changes in traits that occur throughout the evolutionary history of species. VENOMventure is designed to teach evolutionary tree reading skills, but also to boost players' interest in science, science careers, and the practical applications of understanding evolutionary trees for solving real modern medical dilemmas. In order to reach diverse audiences, the game was also designed to be bilingual (Spanish/English) and portable. All of the game props and components, including the inflatable science research trailer that houses it, pack down into crates which can be shipped to different host sites, allowing the game to reach audiences in both rural and urban areas across the United States.

> *It's just so different from what our museums have traditionally done in the way that we've shared information about evolution. It's unique and different. It's invited new partnerships that also are really positive for our museums. And it just feels nice to have this completely creative, fun thing that draws from activities that the team enjoys around games and escape rooms.*
>
> \- Project PI

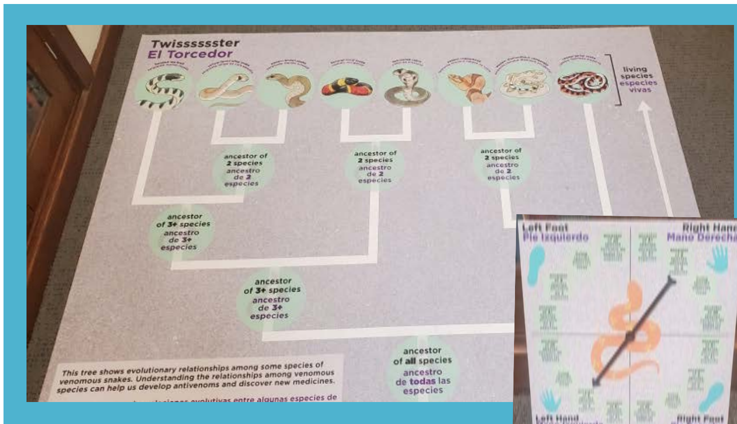
One of the wooden crates that holds VENOMventure for travel from site to site

Project Timeline

The VENOMventure project kicked off in the summer of 2019, and the project PIs began collecting feedback from families and after school groups on initial concepts and paper-based activity prototypes by fall of the same year. While the COVID-19 pandemic caused some refiguring of the project schedule, the project remained largely on track, and additional rounds of formative testing were conducted by the team's research and evaluation partner, Rockman et al Cooperative (REA) in 2021 and 2022 as puzzle ideas were solidified and the game design progressed. The game was finalized and all props were completed in time for unveiling to the public at Berkeley Public Library in June 2023. This report presents findings on the game's learning and engagement impact based on data collected at the first four sites it visited: Berkeley Public Library (Berkeley, CA), Stanislaus County Library (Modesto, CA), the California Academy of Sciences (San Francisco, CA), and the University of Kansas Natural History Museum (Lawrence, KS).

Game Design and Experience

VENOMventure players are introduced to the game by a host site staff member, who first invites them to play an introductory activity called Tree Twisssssster. Tree Twisssssster eases players into reading evolutionary tree diagrams as they struggle to stay upright in a clever rendition of the original Twister game. Once they are warmed up, the group is walked through some basic information about escape rooms (such as how a combination lock works) and then moves on to the escape game. VENOMventure takes place inside an inflatable trailer that represents the research lab of Dr. Leticia Lopez, a scientist who studies fantastical creatures. Groups begin by watching a desperate video message from a staff member at a local hospital, talking about a new species of venomous plant studied by Dr. Lopez and the rash its bite causes. Players must find the information to create the appropriate antivenom in Dr. Lopez's lab, before the power in the research trailer runs out. The clock starts ticking, and players have 45 minutes to complete a series of puzzles that unfold in true escape game style with patterns, locks, diagrams, tech, teamwork, and a little bit of tension and frantic energy thanks to the time pressure.



Tree Twisssssster warm-up game

Research Questions

Our research on VENOMventure explores questions about the design, educational value, and engagement value of an escape game infused with biomedical themes and evolutionary tree concepts. Specifically, we set out to answer the following questions:

Fun, Engagement, and Adult/Child Gameplay Style

- What features create an engaging escape room experience?
- What did families take away from playing VENOMventure?
- How do adults and children work together in the escape game? Do children or adults tend to drive the experience, or is their work collaborative? How does the balance of child and adult gameplay affect learning outcomes?

Learning

- How can an escape game support learning about biomedical science?
- Does the game lead adults and children to interact with science concepts in meaningful ways?
- Does VENOMventure increase understanding of evolutionary relationships and phylogenetic concepts?
- What specific concepts did participants learn through the game?
- Do learning outcomes persist in the weeks after players experience VENOMventure?

Awareness and Interest

- To what extent does VENOMventure increase participants' awareness and interest in science and evolutionary biology?
- To what extent does VENOMventure increase participants' awareness and interest in biomedical research and careers?
- To what extent does the experience support self-efficacy related to science?

Methods

Collecting data on the efficacy and outcomes of VENOMventure for game participants was a thought-provoking challenge thanks to the uniqueness of this experience. Some of the fun and difficult variables that influenced our data collection strategy were:

- The escape room's travel from site to site
- The need to collect data on both adult and child experiences
- The fast-paced nature of the gameplay – Participants move quickly, think quickly, and sometimes solve puzzles quite quickly
- The extended time it takes to play the game – Participants are sometimes mentally and physically fatigued by the end.
- Observation challenges, which include the walls of the inflatable trailer, the noise of the fan, and the need to keep eyes and ears on multiple players, sometimes solving simultaneous puzzles

To tackle these challenges, the research team collected data in two phases. **Phase 1** used a mixed methods approach that incorporated surveys, interviews, observations, and a reflection banner where participants could write their ideas in an open-ended format. We kept the surveys and interviews brief, to reduce the overall time of the research appointments, and snacks, drinks, and seating were provided after the game so that participants could relax while they completed their research activities. A total of 51 groups and 174 individuals took part in Phase 1. Phase 1 participants also received a follow-up survey by email and text message to study the long-term effects of the game. This survey again included the evolution tree quiz, as well as questions about any follow-up behaviors – such as talking about the game with friends or reading the comic book that was sent home with participants. This survey was distributed one month after their participation in VENOMventure. Sixty-six individuals responded to the follow-up survey. **Phase 2** included only the pre/post survey, administered by host site staff when the research team could not be present. A total of 84 groups and 292 individuals took part in Phase 2. (Additional information on sample sizes can be found in Appendix B: Sample Sizes, p.46.)

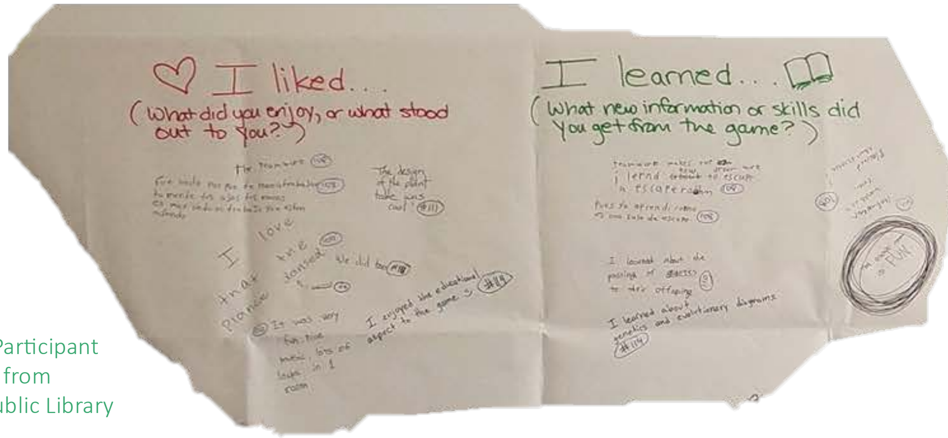
Pre, Post, and Follow-up Surveys

All participants took a pre-survey before being introduced to the game (see instrument in Appendix A, p. 40). The survey included five knowledge items (each worth one point) that required participants to interpret evolutionary trees. Each of these items corresponded to concepts addressed through the escape room puzzles. Participants also responded to an open-ended knowledge question ("What kinds of information do you think these diagrams show?") and rated their confidence in their responses. On the post-survey, participants completed five diagram questions that mirrored the same concepts covered on the pre-survey, responded to the same open-ended question, and again rated their confidence in their responses. They also completed a small number of attitudinal and self-report Likert questions about their game experience. The surveys used simple language so that they would be accessible to those in our target group (ages 9-13) through adulthood. The post-survey was completed at the very end of the research appointment, after participants had completed the group interview and reflection banner. The follow-up survey sent to Phase 1 participants one month after they played the game included the knowledge quiz a final time (again with questions that were parallel, but not identical to the previous surveys). This survey also asked about any longer-term impacts of the game and if participants had used the supporting resources and comic book. A small number of participants also did a phone interview with a researcher, but these were eventually eliminated and replaced with open-ended questions on the survey (see

A researcher poised to start another escape game observation session

Appendix A: Instruments, p. 40).

Observations



Banner of Participant Reflections from Berkeley Public Library

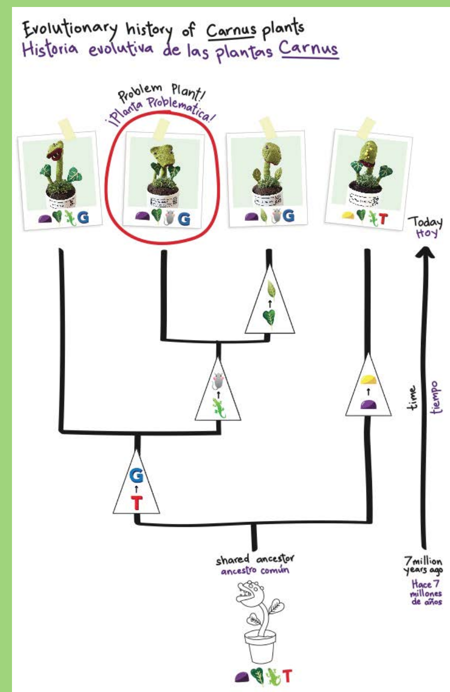
Formative testing showed that collecting conclusive observation data on gameplay learning and strategy might be challenging, so the research team chose to focus on a limited number of variables. Observers used a form to document 1) the balance of adult versus child-led activity in solving each puzzle, 2) participants' use of vocabulary tied to the science concepts in the game, 3) the use of hints or answers to solve puzzles, and 4) basic game stats like the number of players and the time it took to complete the game. Observers also took notes on interaction and conversation related to learning, such as moments when participants traced their fingers along the tree diagrams, explained concepts to one another, or asked scaffolding questions to help another player solve a puzzle.

Reflection Banner and Post-Interview

When game play was done, Phase 1 participants sat down at a table with banner paper laid out and five reflection prompts written across the top:

- ❤️ **I Liked…** What did you enjoy or What stood out to you?
- 📚 **I Learned…** What new information or skills did you get from this game?
- 🌟 **I Wish…** What could be added or changed to bring science alive for you and others?
- 👥 **We did it!…** Give an example of how you worked together.
- ❓ **I wonder…** Did this game make you think about something that you want to explore more?

Participants were given markers and pens and asked to write their thoughts in response to these prompts. They could also "upvote" responses left by previous groups. A researcher then talked through the prompts with participants, eliciting further information. After getting these reactions from participants, the researcher moved on to the second part of the interview, which focused on children's understanding of the evolutionary diagrams used in the game. A researcher would present the Carnus plant diagram from the game (shown at right), and ask participants in the target age range to explain various parts of the diagram and what they represent.



Carnus plants evolutionary diagram

Data Cleaning and Coding

Surveys

Survey data was cleaned by first removing any unmatched pre/post surveys and removing the one instance where a parent and child had completed a form together, instead of individually. Attitudinal survey items where participants had circled more than one answer (e.g. "Not sure" and "Yes") were recoded using a conservative approach, selecting the lesser level of agreement. Participants' ages were coded as either within the target age range (9-13 years), younger children (6-8), older children (14-17), and adults (18+). When statistical tests found that older children and adult responses did not show meaningful differences, these two groups were combined. The tree diagram items were coded for correctness, worth between 0 and 1 points each. The sum of these five questions was the participants' "Knowledge Quiz Score," with a maximum value of 5. The open-ended knowledge item was not included in this score, as it was frequently left blank. This item was also coded for correctness. Full credit (1 point) was given to answers that referred to the relationships conveyed in the diagram between ancestors and descendants, although participants did not have to use these exact terms. Partial credit was given to responses that mentioned evolution, lineage, or ancestry, but didn't refer to the ways different organisms on the diagram are connected. Further information on open-ended coding can be found in Appendix D, p. 51.

Observations and Interviews

Observation notes on each individual puzzle of the game was summarized into two new variables which described a group's overall game strategy or experience:

- **Child/Adult balance** represents the extent to which children versus adults led the puzzle solving. Each of the seven game puzzles was rated as adult led (-2), mostly adult led (-1), equally led (0), mostly child led (1), or child led (2). These scores were added together to get the total child/adult balance, with possible scores between-14 and 14.
- **Puzzle Success** represents how many puzzles participants solved without taking hints or answers.

Documenting vocabulary use during gameplay presented a challenge, with some groups being more vocal than others, and larger groups being more difficult to observe than smaller ones. The resulting data was deemed too inconsistent for a structured analyses or comparison between teams; however, we did notice certain connections between the puzzle concepts and the vocabulary used (see Puzzles, p. 34).

Interview responses to attitudinal questions (e.g. "What did you enjoy about the game?", "What did you learn?") were coded by themes that emerged from the data. Responses to questions about the evolutionary diagram used in the second part of the interview were coded for themes and correctness. An explanation of the themes for each of these items is presented in Appendix D: Coding Open-Ended Responses, p. 51.

Statistical Analysis

Survey data was analyzed to look for significant differences between pre, post, and follow-up knowledge scores, as well as differences in knowledge and attitudinal items by age, site, previous escape room experience, and various gameplay factors. Owing to the very small number of Spanish-speaking participants, we did not look for differences by language. We used an alpha level of .01 for all statistical tests.

Player Engagement

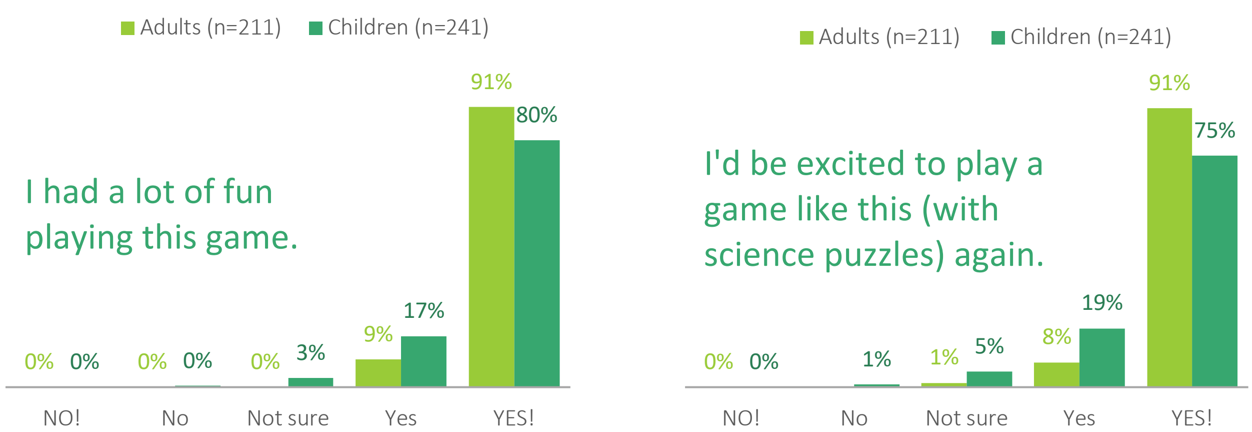
Do players enjoy VENOMventure?

Observations of families playing the game and participants' responses in interviews and on surveys have all shown that VENOMventure is great fun. Participants were highly engaged with the puzzles and smiled and laughed as they discovered different elements – from phylogenetic trees of fantastical animals to animatronic plants that dance and talk. Participant agreement with the statement, "I had a lot of fun playing this game," was extremely high on the post-surveys – 100% for adults, and 97% for

A mom and daughter solving one of the final game puzzles at Berkeley Public Library children (Figure 1). Similarly, almost all of the adults and children surveyed said they would be excited to play a similar game with science puzzles in the future.

When asked about what made hosting the escape game worthwhile, one library staff member stated, “I think, for me personally, it was seeing the joy in people's faces as they experienced it- like all ages. I mean, there were kids who loved it. There were seniors who just had a blast.” This statement aligns with researcher observations from the Phase 1 sites. Almost all participants, regardless of age, actively engaged with the puzzles and seemed eager to do so. In one case, a grandmother indicated she intended to sit back and let her daughter and grandson take the lead in the game. Within a few minutes of watching the puzzles unfold, however, she was up out of her seat and offering advice. Her grandson commented on how the game got a hold of her during the post-game interview: “Once Nonny was up, she was in it.”

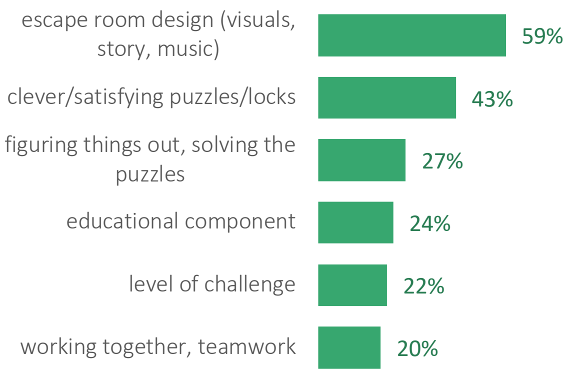
Figure 1. **Post-Survey Engagement Questions**



What features create an engaging escape room experience?

During the post-game interviews, researchers talked with participants about what they enjoyed about the game. Their responses point to a myriad of features that made VENOMventure entertaining - including above all, the dancing plants. Each groups' responses were coded for common themes (Figure 2), and additional supporting information on what makes a successful educational escape room was pulled from observations and comments in response to other interview questions.

Figure 2- Post-interview coded responses:
What did you enjoy, or what stood out to you?
(n=51 groups)



43% of participant groups talked about the dancing plants in their post-game interviews.

Design, Whimsy, and Fun

Interviews and observations showed that the aesthetic design elements of VENOMventure - the graphics, the props, the music, the tone of the game - played a very important role in players' experiences. On encountering the pop-up trailer, participants were immediately intrigued and eager to see inside. Their interview comments also frequently included references to the game graphics, the use of humor, and the whimsical feeling of the experience. "It was really creative. I enjoyed that aspect of it," one adult said. Another commented, "Just from an immersive perspective, building in the sense of whimsy and playfulness is a great way to set the mood and draw people in, especially kids." Every reflection poster that participants completed included multiple references to the games' dancing plants. This is a surprise feature of the game. When participants successfully complete one of the puzzles, dance music suddenly starts playing and the animatronics burst into movement. "It's like you won something!" one participant said. Other participants talked about ways the game incorporated humor, like the bag of unicorn manure, the names of the carnivorous plant species (*Carnus crunchii*, *Feedme steaki*, etc), and the fact that the antivenom is "brewed" using a coffee pot. Even sending the venom off via the mailbox at the end brought a special satisfaction to players.

> *I appreciate how someone built that little box table thing. It was cool! How little planks popped up, and the plants danced, and the plants made different sounds for the foods.*
>
> Adult participant

Clever Puzzles

These thoughtful design choices also carry over into the games' puzzles, which players appreciated. While functionally an escape room can work with very simple puzzle apparatuses – e.g., a series of locks and codes, or even paper-based puzzles - VENOMventure uses a variety of puzzle and prop types to enhance the experience, and players noticed and commented on this. Many participants, as well as host site staff, admired the design of the plant matrix table, with its compartments that pop open one by one as players uncover the traits of the carnivorous plants. A host site staff member talked about the tactile satisfaction of flipping switches on one puzzle, and having to use a QR code scanner on another. The game also uses RFID technology, radio signaling, and pressure plates on certain puzzles, videos, and circuitry. Participants' surprise in discovering how each puzzle functioned enhanced the overall game experience.

> *I liked how you add the different clues together to solve it. The table gave the key to the lunch box that gave the key to the food and opened the next one.*
>
> Child participant

Some players also noticed that the puzzles in VENOMventure were designed well to avoid unnecessary confusion or red herrings. One participant talked about the use of sign posting through images and colors. "It was always very clear what lock went with what data, so you could focus on the concept instead of wondering what was missing," they stated. This was an intentional strategy of the game design. Finally, one player said they liked the way that some puzzles were layered and cumulative - in other words, you might have to solve a few different riddles before unlocking the answer to a larger puzzle.

Scaffolded Learning that Works for Multiple Ages

Two brothers laugh as the animatronic plants break out their dance moves

Part of the reason that VENOMventure uses cumulative layers of puzzles is to walk players through the steps of reading an evolutionary diagram, adding different scientific concepts with each puzzle. Earlier puzzles start with simpler phylogenetic concepts (see

Puzzles , p. 34), but by the final puzzle, players are applying several concepts together in order to successfully interpret the venom tree at the end. Several adult participants noticed and commented on the way that VENOMventure teaches phylogenetic concepts through the puzzles, including a pair who own and operate their own escape room business:

> *Adult 1: What's great about this room is the same thing we try to do in our escape rooms - the idea of progressive learning... learning to solve puzzles that are more and more complicated by starting out simple and going forward. I think that's a great way to teach a complicated concept.*

> *Adult 2: I liked that it focused on a singular concept and presented the information in multiple ways, in multiple dimensions, so that you could test your understanding of the concept by layering it and thinking about it with different symbols and subtly different shifts in the way you present the same concept, which is what I know to be successful in terms of building a deeper understanding of a concept.*

Another adult participant commented that no one in their group had really known anything about evolutionary tree diagrams before playing the game, but they learned "as a by-product of playing." Even children sometimes noticed and commented on the relationships between the different puzzles and how they presented information. One child commented, "I liked that every puzzle was different in its own way but added up to the same thing."

Participants also felt that VENOMventure presented the right level of challenge. While younger participants might not have absorbed all of the information in the course of gameplay, they were able to contribute and try out ideas as they solved the puzzles. The puzzles were also challenging enough to hold the interest of teenagers and older adults who played:

> *It wasn't frustrating, but it was hard." (child participant)*

> *Even if younger kids didn't understand all of it, they're going to get an idea of what this is about. And older kids or experts, they still have to solve the puzzles to go on to the next clue. (adult participant)*

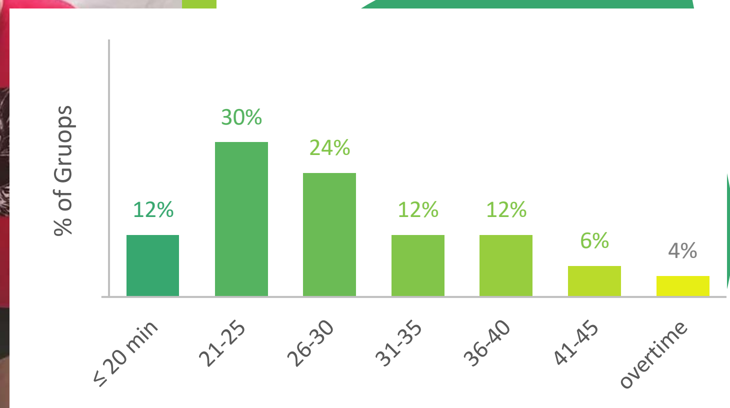
Observations of groups tackling the puzzles in VENOMventure showed that many times, parents and adults would help scaffold the experience for younger members of their group, making comments and asking questions that helped children think through the puzzle:

> *You gotta follow it up. What's common with these two (adult scaffolding Venom Tree puzzle)*

Ok, how you put your finger here and trace backwards to the oldest ancestor. (adult scaffolding Cephalopod puzzle)

A family watching the puzzle table pop open

gure 3. **Time to Complete Game**
(Phase 1 Groups, n=50*)



*Time information was unavailable for one group

Adults would also often trace their fingers along the diagrams or call attention to particular features, like the timeline arrows. Almost all adult participants would read the instructions aloud to other group members at some point in the game, whereas children did this much less frequently. It may be that younger participants tended to read the instructions silently to themselves, but it often appeared that they would jump into trying to solve a puzzle, and then slow down to read the instructions if they encountered an obstacle. We should also note that while adults and older children often read the evolutionary tree puzzles more easily, this was not the rule for every group. On several occasions, we observed adults making a mistake or showing hesitation, while a child in the group demonstrated understanding and solved a puzzle correctly.

While many participants described the experience as challenging, all but two of the observed groups were able to finish all of the puzzles successfully within the 45-minute time limit, often with a comfortable amount of time to spare (Figure 3). The average time to complete the game was 28 minutes and 4 seconds (*SD* = .005). This is further evidence that VENOMventure achieved the right level of challenge for participants. If the puzzles had been more difficult and more groups had failed to succeed within the time limit, their satisfaction with the game would likely have been lower. Furthermore, the puzzle hints and answers which were provided to players as a back-up if they got stuck often went unused. Over half of the groups completed the game without using any hints or answers at all. Only nine of the 51 Phase 1 groups took more than one hint or answer to complete the game.

What did families take away from the experience?

Participants who took part in follow-up interviews or surveys in the weeks after playing VENOMventure were asked about what they remembered about the game and what they took away from their experience. Their comments and responses show a lingering fond memory of the game and their experience playing it. They remembered the fun they had playing, the excitement of figuring out the puzzles, and the design features highlighted above (like the dancing plants and inflatable trailer). Besides the general fun and enjoyment they described, some participants also said the experience had piqued an interest in pursuing future escape room activities. One participant commented, "My son now loves escape rooms and solving puzzles." Another individual (from the Modesto participant group) said they wished they had more experiences like this available to them in their area.

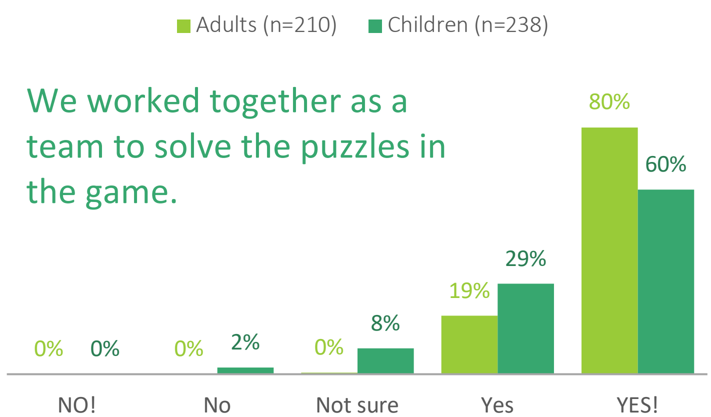
A few participants also talked about the educational experience of the game. One talked about having to "think outside the box," and another described it as "a great mental, physical exercise and a great way to learn about science." Several parents mentioned that this was a great way for children to learn science concepts and that they wished their children could have more opportunities like this:

> *I would like to see these kinds of ideas and projects in libraries and classrooms because they are needed. For my kids especially because they don't get science education like this.*

> *I don't know if my daughter became more interested [in science] but I'm sure she would prefer to learn this way. I know she would also be interested in science in this kind of structure.*

A number of adult participants also talked about how they enjoyed the escape game as a collaborative family experience. One individual mentioned that there aren't many occasions for families to interact in this way. Another commented, "To us, it was really an amazing and wonderful experience because we got to do it as a family." The vast majority of adults (99%) and many of the children as well (89%) also agreed that their group worked together as a team to solve the puzzles in the game (Figure 4). This positive teamwork experience was clearly one of the main appeals of the VENOMventure experience for many participants.

Figure 4. Post-Surveys
Participants' Thoughts on Teamwork



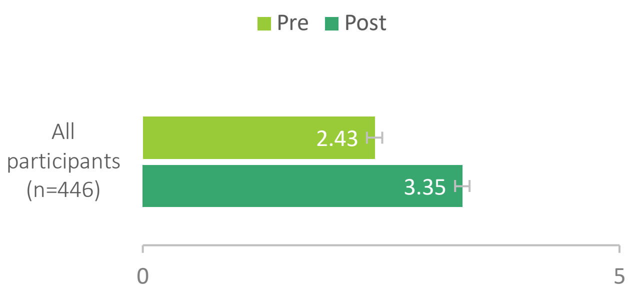
A family works through the Plant Matrix Puzzle

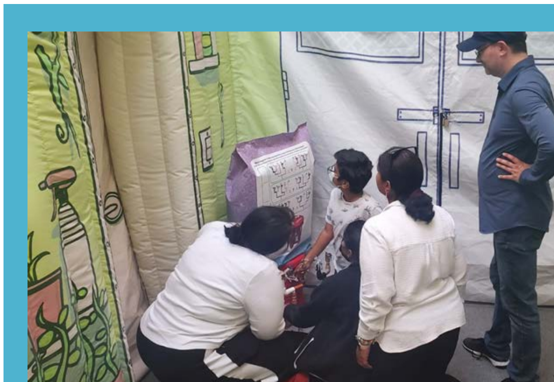
Escape Game Learning

Understanding of Evolutionary Trees

Each puzzle in VENOMventure was carefully designed to introduce players to specific concepts related to reading evolutionary tree diagrams, with the goal that through this fun, immersive, gameplay experience, players would develop an understanding of these diagrams or improve their existing tree-reading skills. Analysis of the knowledge items on participants pre/post surveys showed that VENOMventure had a positive effect on participants' ability to interpret phylogenetic trees. Participants' knowledge quiz scores showed a significant improvement [$t(446) = 14.41$, $p <.001$], with participants getting approximately one more question right on their post-surveys ($M = 3.35$, $SD = 1.6$) than they did on their pre-surveys ($M = 2.43$, $SD = 1.7$).

Figure 5. Pre/Post Knowledge Quiz Scores

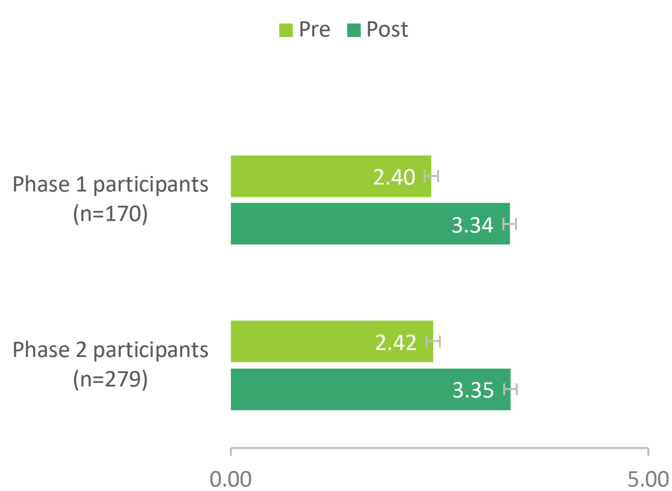




A family studies a tree diagram in the game

To ensure that learning gains were not related to the research experience (i.e., to check if answering researchers' interview questions or participating in the post-game banner reflection exercise resulting in additional learning), we compared survey results from Phase 1 and Phase 2 participants. The two groups did not show significant differences in their quiz scores, however. Phase 1 participants' pre knowledge quiz scores ($M = 2.40$, $SD = 1.74$) were not significantly different from those of Phase 2 participants ($M = 2.44$, $SD = 1.66$), [$t(444) = -0.249$, $p = .323$]. The two groups also exhibited similar improvement from pre to post [Phase 1 $M = .93$, $SD = 1.40$; Phase 2 $M = .94$, $SD = 1.32$; $t(444) = -.139$, $p = .891$].

Figure 6. Pre/Post Knowledge Quiz Scores by Research Phase



Participants also did slightly better responding to the question, “What kinds of information do you think these diagrams show?” on their post-surveys. Average scores for this question went from M = 0.60 on the pre (SD = .36) to M = 0.69 on the post (SD = .29) – also a significant difference [$t(323) = 5.19$, $p < .001$]. Example responses to this question and the ways they were scored are shown in Table 1 below.

Table 1. **Example responses to survey question, "What kinds of information do you think these diagrams show?"**

On the right track (0.5 points)	Getting warmer... (0.75 points)	You got it! (1 point/full credit)
genetics? the history behind animals How we are connected in life	Evolution of traits over time Genetic traits inheritance The evolution of animals When splits between species occurred + what they were	Evolutionary trees, ancestry patterns Genealogy and DNA passed down I think they show the changes in a family tree of animals over time via evolution.

Individual Tree Concepts

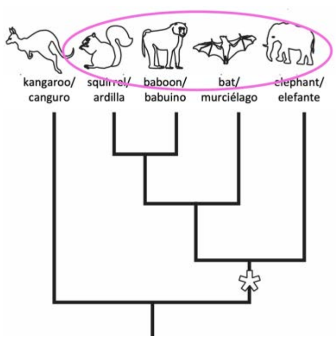
The puzzles that appear in VENOMventure are designed to present basic principles of phylogenetic tree reading, first individually, and then in more complicated puzzles that combine multiple concepts. Likewise, each knowledge item on the surveys is designed to test understanding of different tree principles, such as the direction of time on an evolutionary tree, the relationships between organisms on different branches, and the inheritance of trait changes along branches. Comparisons of participants’ scores on each individual item showed a significant improvement from pre to post survey, both in the total participant sample and in the target group of children ages 9-13 (see Table 2, next page).

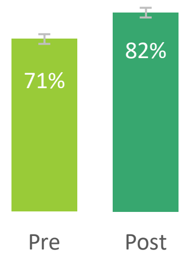
Not all questions were equally difficult for participants. Participants seemed to have an easier time understanding how branches represented relationships between ancestors and descendants (questions 1 and 2), but a more difficult time with items that rely in part on an understanding of the direction of time on a phylogenetic tree (questions 3 and 5). Most of the tree puzzles presented within VENOMventure include a time arrow next to the diagram – a feature which has been shown to aid interpretation. The diagrams on the survey; however, did not include an arrow, since this would immediately reveal the answer to certain questions. During participants’ post-game interviews, children were also asked about the direction of time, using the *Carnus* tree as an example (which also included a time arrow). Just over 80% of the participants answered these questions (aided by a time arrow) correctly, but when they completed their post-surveys a few minutes later (with no time arrow) only 57% of children in the target group (ages 9-13) correctly circled the animals alive today (question 3), and only 61% correctly identified the shared ancestor (question 5). This finding is consistent with the literature on best practices for presenting evolutionary trees and suggests that participants may perform even better on the knowledge quizzes when trees are presented according to established guidelines. Also, although these quiz items were developed through testing with pilot participants, phrasing the items in a clear manner without jargon was a challenge. Some of the difference in performance between the interview and quiz items may have been related to the design of the quiz items.

Table 2. **Participants' pre/post performance on individual knowledge quiz items***
Total Sample, n=446

Knowledge Question	Percent Correct	Knowledge Question	Percent Correct

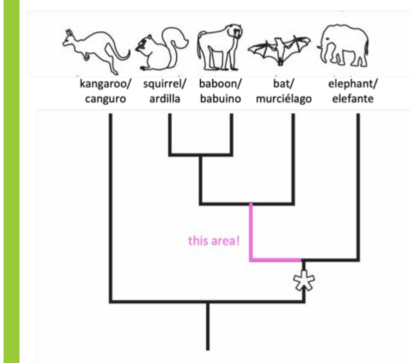
Q1 – Circle all the animals alive today that came from the branch with the star.

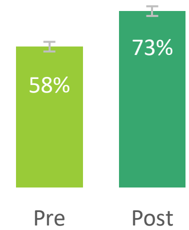




t(444) = 4.23
p <.001
pre *M* = .71, *SD* = .46
post *M* = .82, *SD* = .44

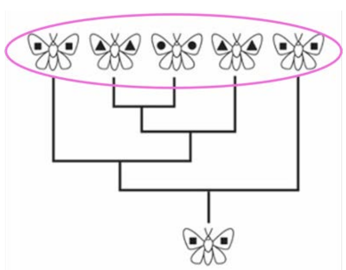
Q2 – Draw an X where the ancestor of squirrels and bats, but NOT elephants, belongs.

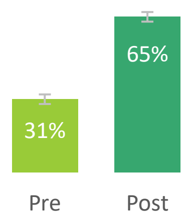




t(444) = 6.69
p <.001
pre *M* = .58, *SD* = .49
post *M* = .73, *SD* = .50

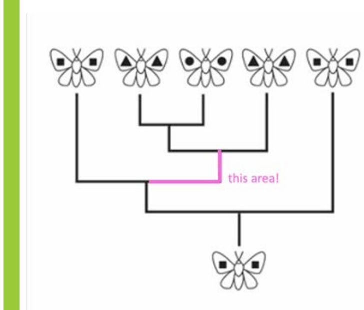
Q3 – Circle all the butterflies alive today.

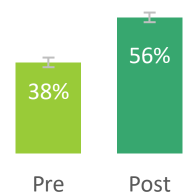




t(444) = 13.30
p <.001
pre *M* = .31, *SD* = .46
post *M* = .65, *SD* = .52

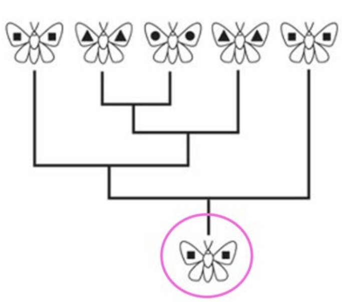
Q4 – Square wings changed to triangle wings just once. Draw an X on the diagram where this happened.

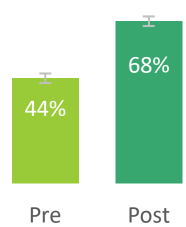




t(444) = 5.61
p <.001
pre *M* = .38, *SD* = .48
post *M* = .56, *SD* = .67

Q5 – Circle the butterfly that is the shared ancestor of the others in the diagram.





t(444) = 7.44
p <.001
pre *M* = .44, *SD* = .50
post *M* = .68, *SD* = .65

*Each survey (pre, post, and follow-up) used isometric items, covering the same five concepts/skills. The example items in this table are drawn from the follow-up survey.

Numbers presented here represent total sample, n=446. Children within the target age group (n=157) also showed significant improvement on all five items at the *p*<0.01 level. (Target group statistics in Appendix C, p. 30)

Learning by Age Groups

VENOMventure was designed with children ages 9-13 and their families in mind. An important part of formative testing of the game puzzles was making sure that they were the right level of difficulty for this age group: hard enough to present a challenge, but not so difficult that children couldn't achieve success within the time allowed and have fun while doing so. Participant feedback during the post-game interviews showed that players liked the level of challenge in VENOMventure and found it to be a good balance (see Scaffolded Learning, p. 15). Depending on where children fall within that age range and what information they've encountered in school, in books, or in other educational family experiences, phylogenetic trees may or may not be familiar. In post-game interviews, we first asked children to tell us what the *Carnus* tree diagram represented, and whether they had learned this today during the game or whether they knew it from previous experience. Forty-three percent of our respondents (n=49), said they had learned these concepts that day during the game. Only two individuals said confidently that they had known this information before. The remaining participants (roughly half) gave mixed responses. Often, participants said they had at least seen an evolutionary tree or a family tree somewhere in the past, but that the game helped them understand it better:

> *I saw something like it before, but we learned it here.*
>
> *I knew a little but not as much as I know now.*

Age was an important factor in participants' understanding. In many of our post-game interviews, older children in the 14-17 age range gave confident responses to our questions regarding the *Carnus* tree. Younger children were less sure, but many were also able to answer the interview questions correctly – sometimes with a small amount of scaffolding from family members.

Statistical analysis also showed that pre, post, and follow-up quiz scores were all positively correlated with participants' age – in other words, younger participants tended to receive lower scores than older participants on all three quizzes (Figure 7).

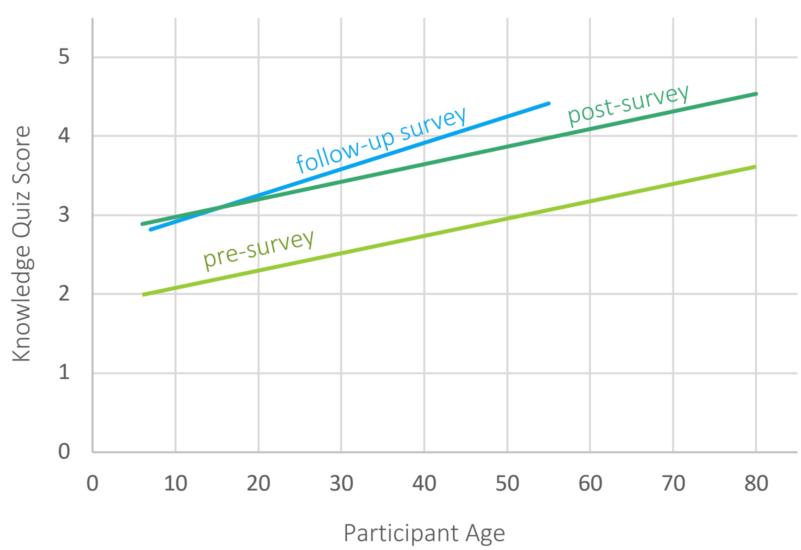
Age x Knowledge Quiz correlations

age x pre knowledge
$r(435) = .24, p = < .001$

age x post knowledge
$r(436) = .25, p = < .001$

age x follow-up knowledge
$r(64) = .37, p = .002$

Figure 7. **Trendlines Showing Correlations Between Age and Knowledge Quiz Scores**



Although understanding of the tree diagrams increased with age, all age groups – including the target group- showed significant improvement from pre to post (Figure 8). These findings suggest VENOMventure is educational for all ages. A one-way between-subjects ANOVA also showed that there was no significant difference in the pre-to-post knowledge quiz improvement shown by these different age groups [F(2,443) = 0.25, *p* = .975]. Each age group showed a similar improvement in their understanding of evolutionary tree diagrams.

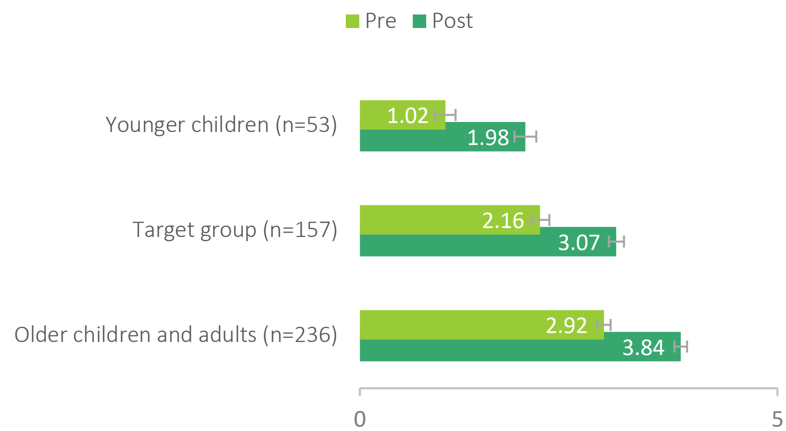
Figure 8. **Pre x Post Knowledge Quiz Change, by Age Group**

Pre x Post *T* Test Results

Younger children
t(52) = 5.977, *p* = < .001
SD = 1.27 (pre), 1.31 (post)

Target group
t(156) = 8.489, *p* = < .001
SD = 1.56 (pre), 1.64 (post)

Older children and adults
t(235) = 10.127, *p* = < .001
SD = 1.65 (pre), 1.39 (post)



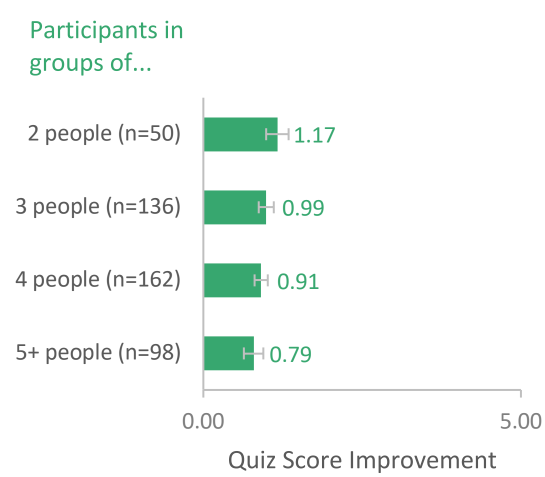
What Other Factors Affect Learning in VENOMventure?

In the dynamic, sometimes chaotic, VENOMventure game experience, many different factors could have an impact on what individuals take away and whether or not participants are able to absorb the science information embedded into the puzzles. Apart from age, we looked at three additional variables to see if there were correlations with participants' learning outcomes: group size, the balance of child versus adult-driven game play, and participants' previous escape room experience.

Group Size

In a larger group, individual participants might have fewer opportunities to work directly on a puzzle. Participants in escape rooms also often take a divide and conquer approach, scattering to work on different puzzles or search in different places for clues. In these situations, would players have a harder time absorbing the information on evolutionary trees? We found that larger groups did tend to show slightly lower improvement in their quiz scores than smaller groups (Figure 9). The difference was small, however, and a one-way ANOVA showed that this trend was not statistically significant [F(3,446) = 1.24, *p* = .30].

Figure 9. Knowledge Quiz Improvement for Participants in Different Group Sizes

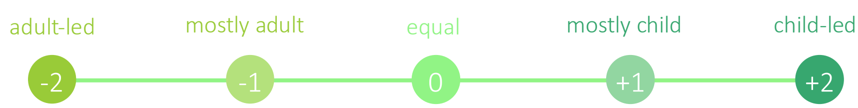


Adult Versus Child-Driven Puzzle Solving

VENOMventure is also designed with family audiences in mind, and we were curious to see how adults and children would interact around the puzzle-solving. Researchers during Phase 1 of the study watched how groups approached each of the seven main puzzles of VENOMventure and assigned a child/adult balance category for each puzzle (Figure 10). These categories were converted to scores from -2 to +2 – not to imply that adult-led puzzle solving was negative, but in order to set zero as our balance point, where child and adult participation was equal. The scores for individual puzzles were then added together, to get a total child/adult balance score between -14 (totally adult-driven) and +14 (totally child-driven).

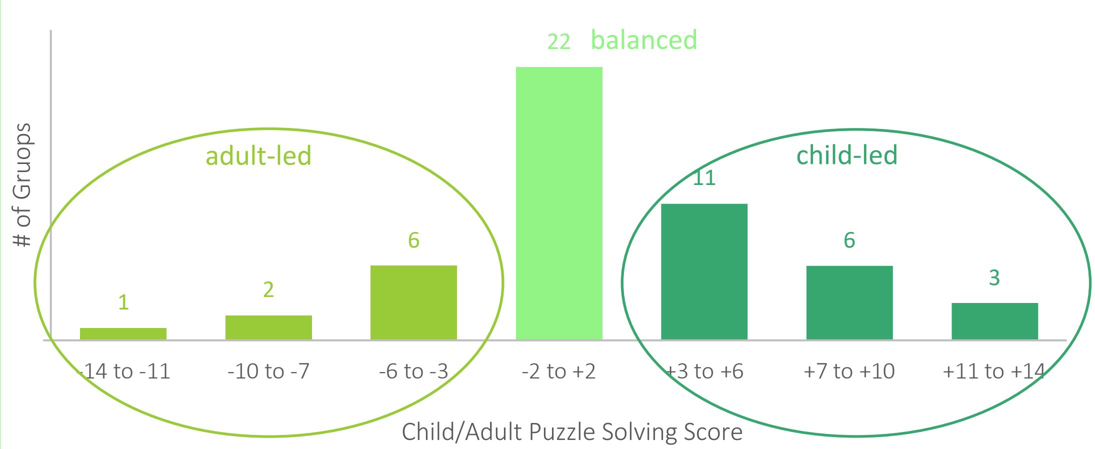
Parents and child solve puzzle together

Figure 10.
Scoring Puzzles for Balance of Adult vs Child-led Puzzle Solving



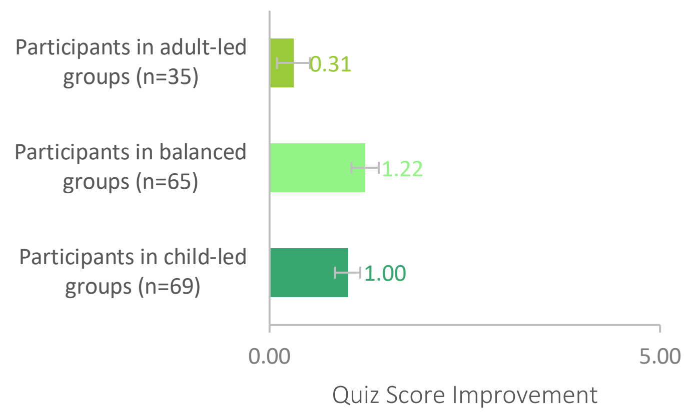
The distribution of child/adult balance scores (Figure 11), shows that many groups clustered around the balance point, with children and adults either sharing the lead in solving the puzzles or taking turns to result in a neutral score. Of the remaining groups, only 18% were on the adult-led side of the scale, while twice as many were on the child-driven side (n=51). These numbers align with patterns we observed during gameplay. Adults in a group would often let a child take the lead, or would offer support by reading the puzzle directions out loud or asking scaffolding questions until a child in the group was able to find the solution. Less frequently, an adult might jump in and solve a puzzle while a child watched, or they might take the lead on a single puzzle while other members of the group were tackling other challenges. After reviewing this distribution of scores, summed the individual puzzle scores to create a new variable to characterize a group's overall approach: adult-led (scores from-14 to-3), balanced (-2 to +2), or child-led (+3 to +14).

Figure 11. **Distribution of Child/Adult-Led Puzzle Solving**



This mix of child versus adult-driven puzzle solving did in fact have a significant effect on how much participants learned about evolutionary trees throughout the game [$F(2,167) = 5.49$, $p = .005$]. Participants in adult-led groups on average showed a smaller improvement in their knowledge quiz scores ($M = .31$, $SD = 1.26$) from pre to post than participants in groups where there was a balance in child/adult gameplay ($M = 1.22$, $SD = 1.40$) and groups where children led ($M = 1.00$, $SD = 1.34$) (Figure 12). These numbers should be read with care, however, since categorizing participants' game play style was not always straightforward due to the wide variation in behaviors observed. This would be an interesting area for further investigation when larger participant numbers and tests for interrater reliability are possible.

Figure 12. **Knowledge Quiz Improvement for Participants with Different Child/Adult Gameplay Balances**

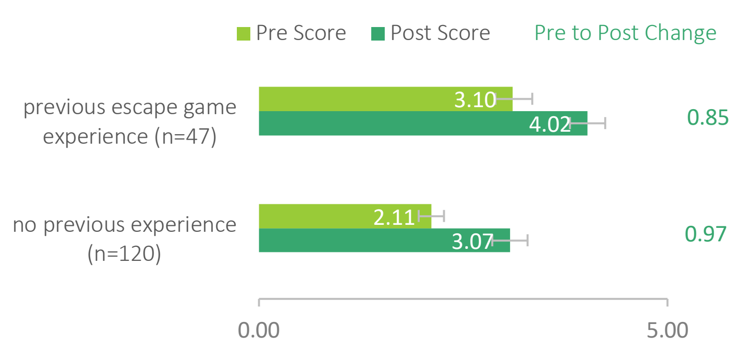


It is also interesting to note that regardless of how researchers scored groups' mix of adult and child-driven puzzle solving, the participants themselves thought their gameplay was very collaborative. Ninety-four percent of participants agreed with the statement, "We worked together as a team to solve the puzzles in the game." In fact, this was one of the things that participants – particularly parents – enjoyed most about the experience (see Player Engagement, p. 17).

Prior Escape Room Experience

The final variable we looked at in relation to participants' pre/post knowledge scores was their prior experience with escape rooms. Participants who have previously tried an escape room game may use different kinds of gameplay strategies than those who have not, based on what they have found to be successful in other escape room games. Some strategies that are often helpful in escape rooms are the divide and conquer approach to teamwork and searching for patterns amongst different items in a room (e.g., repeating colors or numbers) that might indicate a link to be made. Our researchers observed that some participants started using these strategies as soon as the clock starting ticking in VENOMventure. We wondered if these kinds of strategies might help or hinder groups in solving the evolutionary tree diagrams, which rely on paying attention to a very different kind of pattern than you might find in most escape rooms. Participants with prior escape room experience might also be more cognizant of the time and feel more rushed, since commercial escape rooms are often designed for a low success rate. In contrast, VENOMventure was designed so that most participants can succeed in the time limit, but participants who don't know how many puzzles remain in the

Figure 13. **Knowledge Quiz Improvement for those with/without Prior Escape Game Experience**



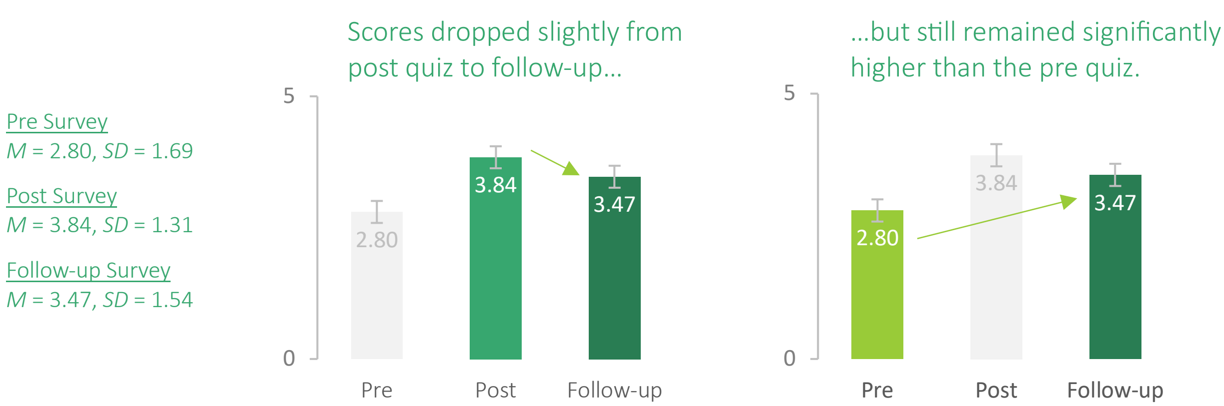
game would not be aware of this. Rushed participants might benefit less from the potential learning value of the puzzles in the game.

In the end, we found that those with prior escape room experience (*M* = 3.10, *SD* = 1.69) did significantly better than those without this experience (pre *M* =2.11, *SD* = 1.69) on the pre quiz [$t(165) = 3.41$, $p < .001$] (Figure 12). Those with prior experience (*M* = 4.02, *SD* = 1.43) also outperformed those without experience (post *M* = 3.07, *SD* = 1.72) on the post quiz [$t(165) = 3.33$, $p < .001$]. This may suggest that those individuals who have done escape rooms before have had more prior exposure to evolutionary tree diagrams. The improvement in their scores from pre to post, however, was not significantly different between these groups [$t(165) = .198$, $p = .842$]. Those with prior escape room experience (*M* = .85, *SD* = 1.48) showed a similar level of improvement compared to those without experience (*M* = .97, *SD* = 1.38). Regardless of whether participants had done an escape room before or not, their learning outcomes were the same.

Longer Term Outcomes

Results from the follow-up survey showed that participants held on to most of their learning gains over the longer term. The follow-up survey was distributed to all Phase 1 participants (n=174) one month after they had played the game, and approximately 39% of these participants responded (66 individuals). The survey contained a set of five knowledge items that again mirrored the items on the pre and post surveys. Participants' scores on this knowledge quiz (*M* = 3.47, *SD* = 1.54) were slightly lower than their post-survey scores, but this was not significant with the alpha used herein (*M* = 3.84, *SD* = 1.31) [$t(65) = -2.18$, $p = .033$]. The follow-up survey scores also remained significantly higher than their pre-survey scores (*M* = 1.80, *SD* = 1.69) [$t(65) = 3.37$, $p = <.001$] (Figure 14).

Figure 14. **Significant Differences Between Knowledge Quiz Scores – Pre, Post, and Follow-up Surveys (n=66)**



It is not unexpected to see a drop in comprehension from post-survey to follow-up, considering that four or more weeks had passed since playing VENOMventure. While the project team provided a number of resources to encourage families to continue to engage with the tree reading skills presented in the game, not all participants utilized these resources (see Follow-up Activities, p. 32), and our sample size for the follow-up survey is too limited to know if these made a meaningful difference for long term learning. Nevertheless, it's encouraging to see that much of the knowledge effect of the game persisted in the weeks after, especially considering the short length of the game intervention. Considering the high levels of participant engagement, it seems very likely that the memory of VENOMventure and a sense of familiarity with evolutionary tree diagrams will persist with the participants for quite some time.

Participants’ Learning, in Their Own Words

In their post-game interviews, Phase 1 participants were fast to describe the many things they enjoyed about VENOMventure (see Player Engagement, p. 12), but they slowed down a little when it came to answering the question, “What new information or skills did you get from this game?” The abstract skills associated with reading evolutionary trees may be hard to put into words. Although their quiz scores show improvements in participants’ abilities to read evolutionary diagrams, only 37% of groups made comments related to this during their interviews (Figure 16). For example, one child stated, “I learned that the ancestry line changes and splits. The ones at the top are alive. Then it splits and becomes different. I learned that from the game.” While they didn’t reference evolutionary trees directly, another 25% of groups made comments about related themes, such as species’ traits, evolution, DNA, or ancestors and descendants. Adding these together, the majority of groups (62%) talked about the science themes embedded in VENOMventure when describing what they learned. When they later responded to a close-ended survey question, even more participants agreed that VENOMventure helped them understand evolutionary trees (Figure 15).

Figure 16. Group Interview Responses, Coded, (n=51)

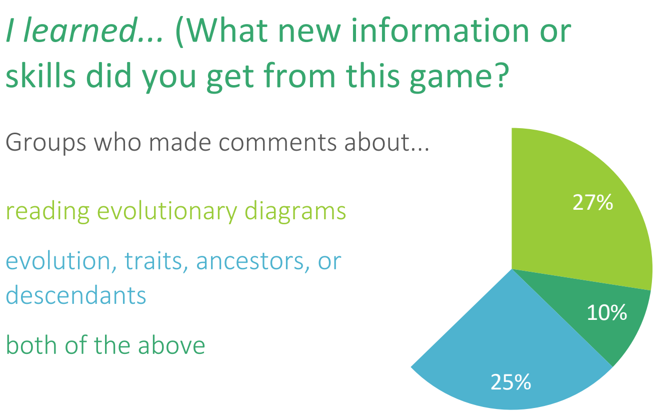
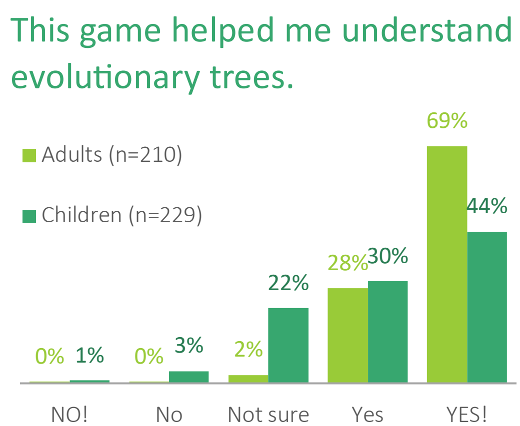


Figure 15. Post-Survey Responses: Self-Assessed Learning



Unsurprisingly, it was often the adults in the groups who spoke about the science concepts during the group interviews. They were also more likely than children to agree that the game had helped them understand evolutionary trees on their post-survey. Parents may have been more clued into the educational content from reading the recruitment materials, or simply because of their age and experience. One parent, encouraging their child to answer the question, “What did you learn…” prompted this amusing exchange:

> *Parent: What was this whole thing about?*
>
> *Child: Saving the world!*
>
> *Parent: …or maybe shared ancestry. (412)*

Some children even admitted that they were focused more on solving the puzzles than understanding the diagrams. “I focused more on figuring out the patterns than reading all the information,” one child stated. “That was more fun.” Another said, "I learned that such escape rooms existed. It's hard to describe what else I learned because I was focused on the fun." Of course, the game learning was embedded within the patterns of the diagrams, so children may just have been less aware of this. During formative testing of VENOMventure, the project team debated how explicit to be when presenting the game's science concepts- for example, should puzzle instructions be more didactic, and state specifically that the diagrams presented are evolutionary trees? In the end, the game was intentionally designed to use scaffolded puzzles rather than to be directly instructive, so that the project could test the potential learning value of an escape game that doesn't rely on traditional teaching techniques. Children may have been less tuned into their learning as a result, but their knowledge quiz scores still show they learned just as much as adults. Their parents and other adult participants also strongly agreed that the game was an educational experience for children (Figure 17).

Figure 17. **Adults' Assessment of the Game's Educational Value for Kids**
(n=194)

STEM Attitudes and Interest

Does VENOMventure spark an interest in or curiosity about science?

A key goal of the VENOMventure escape game is to spark participants' interest in and curiosity about evolutionary science and science in general, embedding science concepts tied to real-world applications in the game narrative and puzzles. Throughout the game, participants are deciphering evolutionary diagrams in order to formulate an anti-venom, just as biologists rely on an understanding of the evolutionary history of venomous animals to develop novel antivenoms and the use of existing antivenoms. While the fun and excitement of solving the game puzzles sometimes seemed to overshadow the medical and evolutionary themes of the experience, reflections shared in the post-game interviews shows that VENOMventure piqued many participants' curiosity about the science topics presented. When asked, "Did this game make you think about something that you want to explore more?" over half of the groups talked about biology concepts related to the game. Forty percent of the groups made questions and comments about evolution, ancestry, or phylogenetic trees, like this father and son pair:

> *Child: I wondered how big could the evolutionary tree get. If you put every species in the whole world, how big would it get?*
>
> *Adult: Or how narrow would it get? What would it start with?*
>
> *Child: It would start with the first thing that ever lived on the earth.*

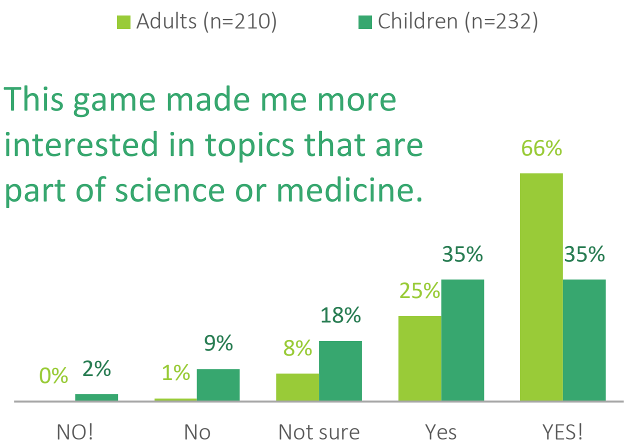
Another 14% of groups made comments about the antivenom storyline of the game or about the idea of curing diseases. Both children and adults seemed intrigued to learn that developing real world antivenoms often involves studying the evolution of a species.

Table 3. **Post-game interview responses to "I wonder" prompt**
(n=42)

I wonder... Did this game make you think about something that you want to explore more?	
Themes: % of Groups	Example Responses
Ancestry and evolution: 40%	The species of different animals alive now versus years ago When one trait is different, how do you tell if it's an early split or a late split?
Escape Games: 29%	Explore more escape games? Will there be another one like this?
Antivenom and curing diseases: 14%	How does knowing the traits help with producing an antivenom? I wondered whether there is really a DNA sequence for antivenom. Whether that is a thing. Whether there is genetic in coding in venom, and that's what helps you made antivenom.

Overall, 91% of adults and 71% of children agreed that VENOMventure made them more interested in topics that are part of science or medicine (Figure 18). Some parents noted in their post-game interviews that their family already had a high level of interest in science, but that they still really enjoyed the experience. One parent commented, “We are a family who’s super interested in anything so even though we didn’t get more interested we thought it was really cool.” Another parent said that while they’re not sure if the game increased her daughter’s interest in science, she knows that her daughter was highly engaged and would enjoy learning science in this way in the future.

Figure 18. **Science Interest and VENOMventure** (Post Survey Responses)



Does VENOMventure spark interest in STEM careers?

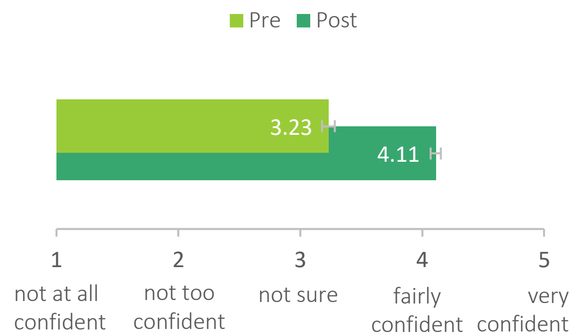
Comic book excerpt with scientist profile

While VENOMventure doesn’t explicitly call attention to science careers in the game itself, a few participants did mention this in post-interviews. One child, for example, commented, "I do want to be a chemist later in my life, so I'll add onto that a venom researcher," and his sibling added, "or a genetic scientist." Another group talked about the connection between the game and the work of real-world scientists in their debriefing interview. One individual, studying the Carnus tree diagram, said in a questioning tone, "I guess that's how scientists figure out diseases… They have to go back to their ancestors to figure out where in that line that problem thing developed that disease." The comic book that participants received after playing draws more attention to science careers, highlighting several real-life scientists and how their work relates to the concepts in the game. While not many of the follow-up survey participants reported reading the comic book, four out of the eleven individuals who did read the comic book said it taught them about science careers. The email with additional resources sent out to game participants was another place that they might have picked up information on STEM careers. Only two individuals said they explored these links, and one of them said they learned about science careers through that information.

Does VENOMventure encourage feelings of science self-efficacy?

In addition to eliciting some new thoughts and interests related to science, survey data suggests that participants also experienced a boost in their confidence related to reading evolutionary trees. After completing both the pre and post knowledge quiz items, participants were asked to rate their confidence in their answers (Figure 19). The average participant response moved roughly from "not sure" on the pre (M =3.23, SD = 1.09) to "fairly confident" on the post (M = 4.11, SD =0.87)- a statistically significant increase [$t(430) = 17.07$, $p < .001$]. We don't know if this improved confidence for tree reading will carry over into other areas of participants' lives where they engage with STEM content, but it is an intriguing area for future research. The project team hopes that the engaging experience participants had playing VENOMventure and the success they felt in completing the science puzzles may give them a self-efficacy boost the next time they run into an evolutionary tree diagram or encounter phylogenetic concepts in school or other contexts.

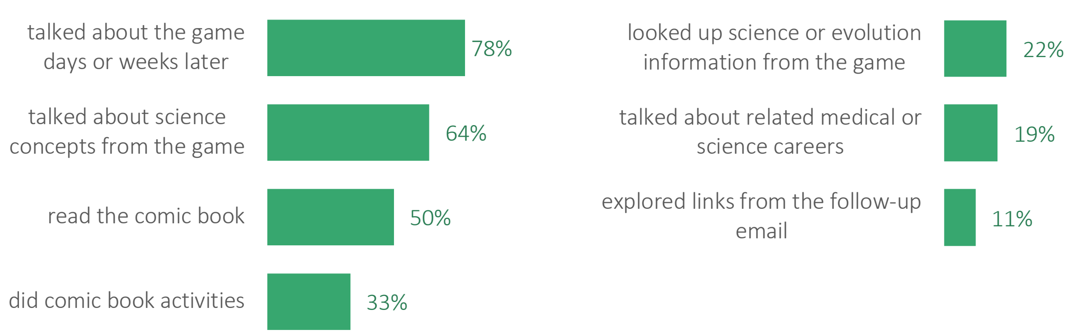
Figure 19. **How confident do you feel about your answers to the questions on this quiz?**
(n=430)



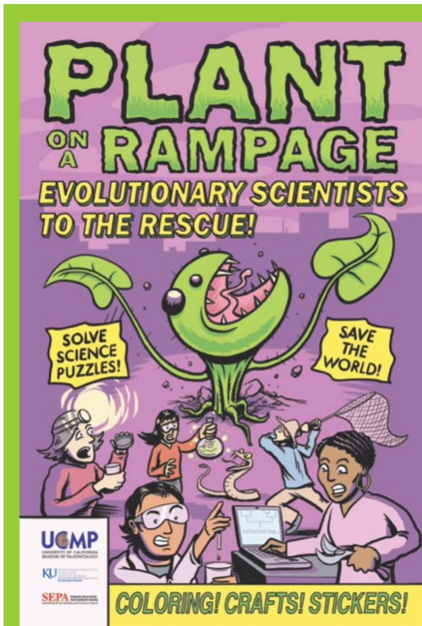
Do players engage in follow-up activities or conversations?

On average the VENOMventure game lasted about 28 minutes for our Phase I participants, but was the experience sufficiently engaging to keep participants thinking and talking about it in the weeks afterward? Responses to our follow-up survey sent out to groups one month after their game appointments shows that 78% of participants did talk about the game in the days and weeks that followed, and almost two-thirds talked specifically about the science concepts from the game (Figure 20).

Figure 20. **Follow-up Activities Reported**
(n=64)



To help enforce the scientific concepts from the game and prolong the fun, the team designed the *Plant on a Rampage* comic book and filled it with phylogenetic tree puzzles, real life scientists and their work, and a storyline that ties into Leticia Lopez and her fantastical venomous plants. The comic book was produced in both Spanish and English and offered to all youth participants after they completed the game. Half of our follow-up survey participants said they had read the comic book, and a third said they did some of the activities it contained. The individuals who registered their group for the game online also received a follow-up email that provided links to supporting activities and resources. Fewer individuals said they explored these links (11%). The physical handout of the comic book was clearly more successful at capturing participants' attention. It is also interesting to note that while people didn't necessarily open the follow-up email they received and view the resources shared there, 22% of participants *did* do their own exploration to find additional information on the science and evolution concepts from the game. On average, follow-up survey participants reported doing at least three different follow-up activities, and only four individuals reported none.



Cover and interior excerpt of VENOMventure supporting comic

Authors: Josh Frankel, Teresa MacDonald, Anastasia Thanukos

Artwork by Josh Frankel

Puzzles and Tree-Reading Concepts

Above we have shown that the overall game experience led to improvement in participants' tree-reading skills, but how did the puzzles in VENOMventure achieve this? Each individual puzzle in VENOMventure presents different concepts tied to reading evolutionary trees and understanding relationships between ancestors and descendants. During Phase I observations of gameplay, researchers tracked the vocabulary players used, their motions and gestures, and other evidence that might elucidate how and when they picked up on different phylogenetic concepts (see Observation Instrument, Appendix A, p. 45).

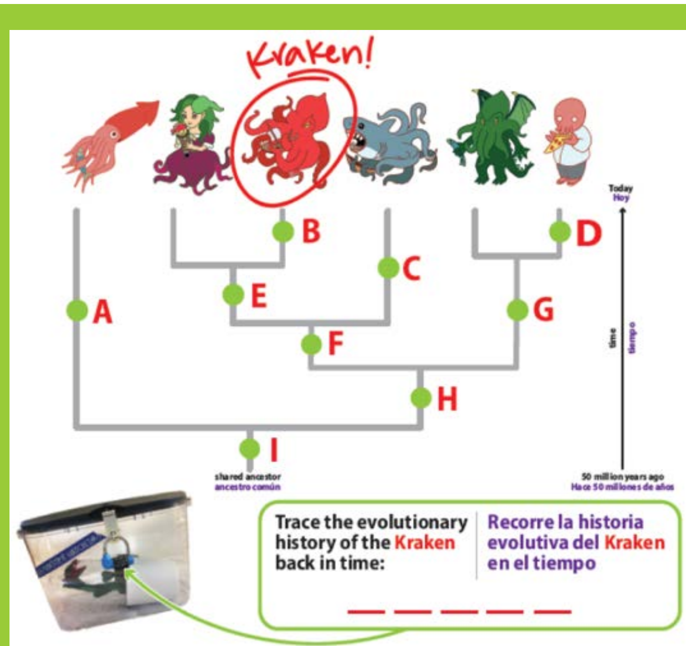
Unfortunately, a number of factors made it difficult to collect consistent and complete data from one participant group to the next. The noise caused by the fan, for example, sometimes made it difficult to hear the conversation between participants, and some groups were simply less verbal than others. It was also difficult to capture thorough information when participants split up to solve multiple puzzles at once, or when a puzzle was out of view of the observer. In an ideal research situation, inviting participants to reflect on each puzzle in a post-game debriefing would provide much richer data on how VENOMventure supports learning. Nevertheless, our observations did turn up some patterns that suggest the different puzzles in the game were achieving their individual aims and that by the end of the game, groups were applying many of the concepts outlined in the learning goals of the puzzles. A description of each puzzle, its learning objectives, and observations of player learning is provided below.

Puzzle 1: Cephalopod Time Tree

To Solve: Correctly trace lineage on a tree backwards in time.

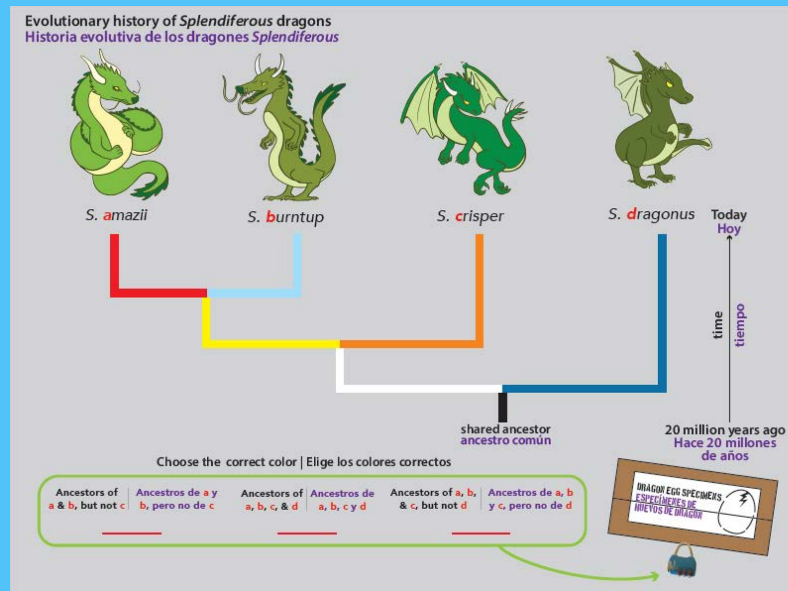
Learning Goal: Players will understand that time on vertical phylogenies flows from roots to tip (i.e., upwards).

Observations: This puzzle was fairly intuitive to players, although players occasionally stumbled over the direction of time in the diagram. Adults sometimes helped younger members of their group by emphasizing the words "back in time" in the instructions, and many participants traced their fingers along the diagram. The mix of adult versus child-led activity on this puzzle was fairly even across our 51 observed groups. We heard many groups refer to "evolution" and "time" as they worked on this puzzle, and a few referred to an "ancestor."



Cephalopod Time Tree

Puzzle 2: Dragon Puzzle



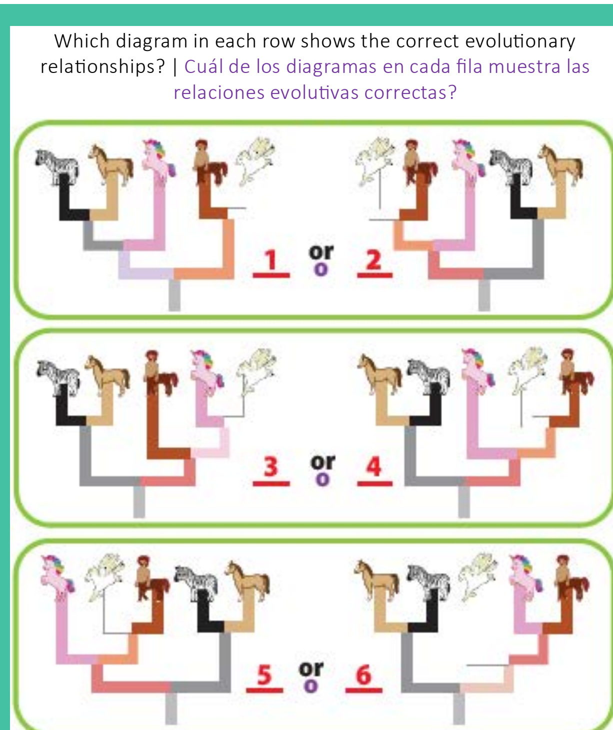
Dragon Puzzle Evolutionary Tree

To Solve: Correctly determine which dragon species share which ancestors.

Learning Goal: Players deduce and then apply the concept that branching patterns on a phylogeny represent patterns of shared ancestry and that single ancestral lineages give rise to multiple descendant lineages.

Observations: This puzzle was slightly harder than the Cephalopod Puzzle. Six groups out of 51 took hints (compared to three for the Cephalopod Puzzle), and many groups got it wrong on the first attempt or asked for help from another member of their group. Even adults sometimes struggled with the puzzle, although many also supported the younger members of their group by reading the instructions aloud and asking scaffolding questions. Many participants also traced their fingers on the diagram, presumably to keep track of the different lineages they were trying to compare. In more than one case, an adult modeled the first part of the puzzle and then had their child do the next one. In one case, a child explained the puzzle to their adult, saying, "Assume that each color is a different ancestor... so the first ancestor is yellow." The word "ancestor" was used repeatedly by groups as they worked on this puzzle.

Puzzle 3: Fantastical Horse Puzzle



Fantastical Horse Puzzle

To Solve: Determine which of the diagrams in each row matches the accompanying 3D model, whose branches rotate while maintaining the same evolutionary relationships.

Learning Goal: Players deduce and then apply the concept/tree reading skill that branches on a phylogeny can be rotated around nodes without changing the relationships depicted by the tree.

Observations: Multiple group members often came together to solve this puzzle, which again seemed harder than the Cephalopod or Dragon Puzzles. Participants took time to read the instructions, study the diagram, and compare it to the 3D horse model. In many cases, it was difficult to tell if all members of the group understood the concept by the time one person opened the lock. Several groups also started by focusing on the traits of the horses in the model, and looking for similarities or differences between them that might be a clue – for example, zebras and horses are real animals, while the others are fantasy creatures. We overheard one group saying, "I don't think it matters which way they're facing," which ties into the key learning goal for this puzzle. Many groups, however, may have needed a little more time with this puzzle for the concept to fully sink in. The vocabulary word we heard most frequently during observations was "evolve" or "evolution," but the word "branch" also came up occasionally.

Plant Matrix Puzzle Switch Board

Puzzle 4: Plant Matrix

To Solve: Correctly identify four different traits for four species of *Carnus* plants.

Learning Goal: Players observe that some species share certain traits and others are unique. This lays the foundation for the next puzzle, in which players see how phylogenies and evolutionary history help explain the trait distributions observed in species.

Observations: While the balance of child and adult-led puzzle solving was fairly even across the previous puzzles, this was one puzzle where children jumped in and took the lead. We suspect that the very tactile nature of this puzzle - which requires placing the different plants on their plates, flipping switches, opening lunchboxes, dangling snacks for the plants, and using a QR code scanner – made it very appealing to children. Parents likely wanted them to have the enjoyment of completing each of these tasks. The Plant Matrix puzzle is also solved through making observations rather than reading trees, and it may have had a lower barrier to engagement for this reason. We heard fewer of our key vocabulary words when observing players tackle this puzzle, although they did talk about the different traits of the four plant species as they worked to solve it, and players were clearly registering the variation in traits in order to solve the puzzle. The word "DNA" was used occasionally when players noticed the chalkboard reading "DNA sequence" and filled in the missing letters.

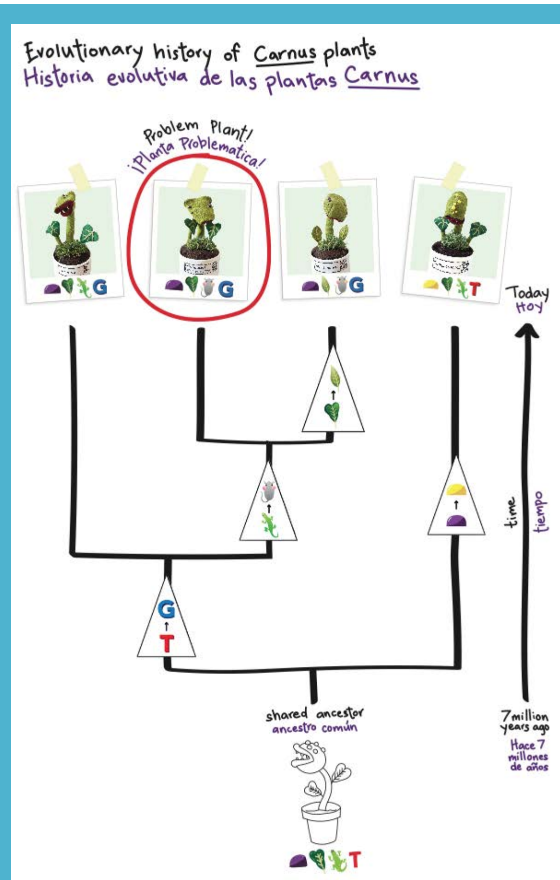
Puzzle 5: Carnus Tree

To Solve: Correctly place four different triangles, each showing a trait change, on the appropriate branch of an evolutionary tree. To do so, players must interpret the diagram and the branching pattern from ancestor to descendants.

Learning Goal: Players deduce and then apply the concept that trait changes occur in an ancestral lineage are inherited by descendant lineages along branches of a phylogeny. Players understand that phylogenies and evolutionary history help explain the trait distributions observed in species (e.g., that the *Carnus* plant traits they observed and "recorded" in the previous Plant Matrix Puzzle evolved from an ancestor as shown in the diagram).

Observations: Players solved this puzzle fairly rapidly, although in many different ways. Some children blazed through it without difficulty and saying very little. Some groups slowed down and talked about it, with adults or older children helping younger children by talking through the diagram and what it represented. In one case, a child explained the puzzle to their mother. Based on the many snippets of dialog we heard, participants were reasoning through this diagram and making the connections it was intended to teach. We heard groups talking about trait changes (although not using the word "trait"), and changes over time or from an ancestor, for example:

- "What's the difference? When did purple [warts] go to yellow?" [Middle child, guiding younger sibling]
- "This is the ancestor who had heart shaped leaves... This is the earliest branch in the evolutionary path, so what is the difference between this branch and this branch?" [Parent helping child]
- "Look at the common ancestor. All three of these are G, so which one..." [Child explaining to parent]

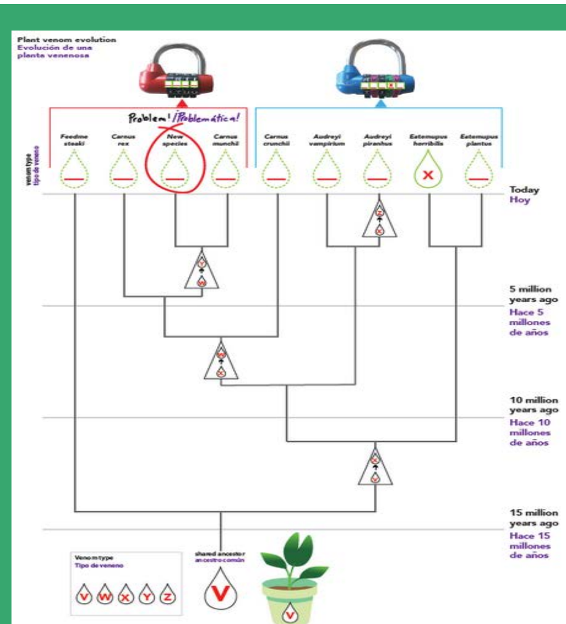


Carnus Tree Puzzle

Puzzle 6: Venom Tree

To Solve: Players observe the changes in the venom type along the branches of diagram and correctly determine the venom type of each descendant plant, placing a corresponding placard in the row at the top.

Learning Goal: This puzzle reverses the task of the previous puzzle and reinforces the concept that trait changes that occur in an ancestral lineage are inherited by descendants along the branches of a phylogeny. Players understand that phylogenies and evolutionary history help explain the trait distributions observed in species – in this case, the distribution of a trait with medical applications: venom type.



Venom Tree Puzzle

Observations: Most groups slowed down when they got to this puzzle, spending more time to study the diagram and arrive at an answer. Occasionally groups were distracted by other features of the room that they thought might come into play in that moment, like the coffee pot or the phone, rather than focusing on interpreting the diagram. When players turned their focus to the tree, there was much discussion, explaining, and moments of uncertainty or confusion before they reasoned their way through. Groups often had to rearrange their placards as they revised their understanding of the diagram. We heard many groups talking through the trait changes, for example, "It started off as V, but right away it turned to X," and "Everything comes from V." We also heard the words "ancestor," "branch," "species," and "mutation."

Puzzle 7: Antiven-o-matic

To Solve: Players must read the Venom Tree diagram they just completed and correctly identify the venom type of the problem plant at four different points in time, entering these on the dials of the Antiven-o-matic. They then brew the anti-venom and watch a video of a test of the antivenom on a mouse (showing an itchy mouse puppet sipping a brewed antivenom through a straw), which reveals whether or not they are correct.

Learning Goal: Players integrate the concept that time on a phylogeny flows from root to tip with their understanding that branches represent ancestral lineages and that trait changes in these lineages are inherited by descendant lineages. Using these three concepts together, they can deduce the pattern of trait changes experienced by the ancestors of the new species throughout its evolutionary history.

Anti-venom-o-matic

Observations: This final puzzle of the game tripped up many groups multiple times as they rushed to complete the escape game. Some groups hurried to brew the anti-venom before reading the instructions next to the dials, but many groups also seemed to struggle on subsequent tries, after they realized they needed to pay attention to time on the diagram. Some groups may not have been focusing on the problem plant in the Venom Tree, although it was difficult to tell due to the placement of this prop. Many groups ended up taking a hint (11 groups out of 51) or the answer (one group) on this puzzle. Despite the challenge of this particular puzzle, all but two groups were able to eventually complete it without directly taking the answer from the help sheet. The team expected this puzzle to be the hardest of the game, as it requires integrating several tree-reading skills participants practiced or learned in prior puzzles to reconstruct ancestral character traits with the time calibration of the Venom Tree. Note that the Venom Tree shows where the changes in venom type occurred on the branches, but it doesn't directly show the venom type along the branches. This has to be deduced by the game players – e.g., by determining that in the time between the V→X change and the X→W change, a species would have venom type X. Another potential challenge with this puzzle is that participants may have been reluctant to slow down and think through the diagram as they neared the end of the game. The vocabulary terms we heard most often on this puzzle were "time" or related terms like "years ago," "past," and "now/today."

Conclusion

The summative evaluation of VENOMventure at the first four stops along its journey has proven it to be a great success – both in terms of player engagement and in supporting the learning goals around which it was built. With very few exceptions, families and groups who played the game took delight in the experience - smiling, laughing, and celebrating all along the way. Multigenerational groups collaborated to solve the puzzles, and we observed many, many examples of individuals explaining concepts to one another, asking questions, and supporting their teammates. By the end of the game, participants showed a significant improvement in their tree-reading skills, showing that – despite the sometimes frantic atmosphere that escape games create – players were absorbing information about how to read phylogenetic diagrams. These knowledge gains held up for both adults and our target group of children ages 9 to 13. Furthermore, participants showed significant improvement on each individual question on our knowledge quiz, demonstrating the range of new information players were taking in during the game.

VENOMventure also piqued players' interest in evolutionary trees and science themes related to the game. While they admitted to being largely focused on the fun of the game and getting puzzles correct, children also said the game increased their interest in science topics, and they reported higher confidence in their tree reading skills after having completed the game. Despite being a brief experience, the follow-up survey also showed that participants were thinking about the game in the days and weeks that followed. Furthermore, they maintained most of their learning gains at the time of the follow-up survey.

Evaluating VENOMventure and observing a wide range of players tackle the game at four different sites has been a joyful and fascinating experience – one that has given rise to many more questions about the possibilities of educational escape rooms. How do group dynamics and different forms of parent support affect the learning experience for younger children? What might happen in a group of only children – especially those of roughly the same age and same level of prior experience with evolutionary trees? Is there a threshold at which group size becomes a barrier to players absorbing the science content contained in different puzzles? These are just a few of the questions we hope future teams have the opportunity to explore.

Appendix A: Instruments

All evaluation instruments were available in both Spanish and English.

Demographics Form (Phase 1 and 2 Participants)

VENOMVenture – Demographics Form **Group #: ________**

Please fill out one form per group. Put the group # from your survey at the top, and thank you!

Please indicate the genders and ages of the people in your group:

Initials (should also be on surveys)	Gender	Age
Person 1: ___________		
Person 2: ___________		
Person 3: ___________		
Person 4: ___________		
Person 5: ___________		
Person 6: ___________		

Please indicate the race/ethnicity of people in your group: (People may identify as more than one.)

	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6
American Indian or Alaska Native						
Asian						
Black or African American						
Hispanic						
Native Hawaiian or Other Pacific Islander						
White						
Other:						

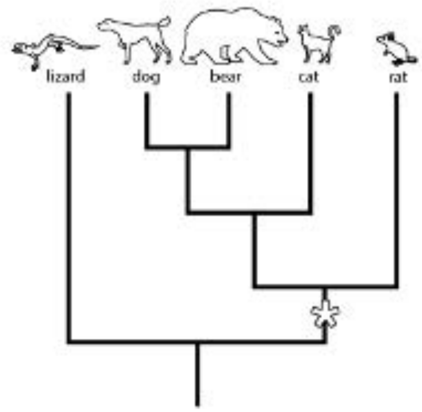
Pre and Post Survey

VENOMVenture! - Game Survey Group # ________

Year 4 Summative Evaluation Participant Initials ________

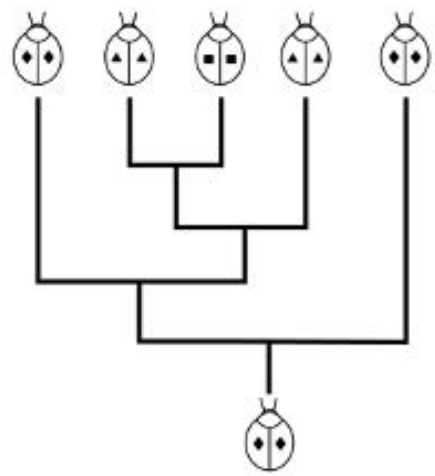
<u>**Draw on the diagrams**</u> **to answer the following items. If you are not sure about an item, it's ok to skip it and check "No guess (not sure)" instead.**

1. <u>Draw a circle</u> around all the animals alive today **that came from the branch with the star**.
   - ☐ No guess (not sure)
2. <u>Draw an X</u> where the ancestor of dogs and cats, but NOT rats, belongs.
   - ☐ No guess (not sure)



---

3. <u>Draw a circle</u> around all the beetles alive today.
   - ☐ No guess (not sure)
4. Diamond wings changed to triangle wings just once. <u>Draw an X</u> where this happened.
   - ☐ No guess (not sure)
5. <u>Draw a box</u> around the beetle that is the shared ancestor of the others in the diagram.
   - ☐ No guess (not sure)



6. How confident do you feel about your answers to this quiz?

Very confident	Fairly confident	Not sure	Not too confident	Not confident at all

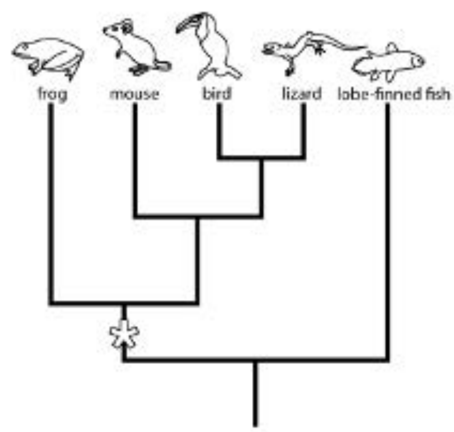
7. What kinds of information do you think these diagrams show?

STOP HERE!!! FINISH THE REST OF THE SURVEY AFTER YOU ARE DONE PLAYING THE GAME

POST-SURVEY - Complete these questions AFTER you finish playing the game.

Circle a response to say how much you agree with the following statements:	YES!	Yes	Not sure	No	NO!
I had a lot of fun playing this game.					
I'd be excited to play a game like this (with science puzzles) again.					
We worked together as a team to solve the puzzles in this game.					
This game helped me understand evolutionary trees.					
This game made me more interested in topics that are part of science or medicine.					
[ADULTS ONLY] I think this was an educational experience for the kids in my group.					

Draw on the diagrams to answer the following items. If you are not sure about an item, it's ok to skip it and check "No guess (not sure)" instead.

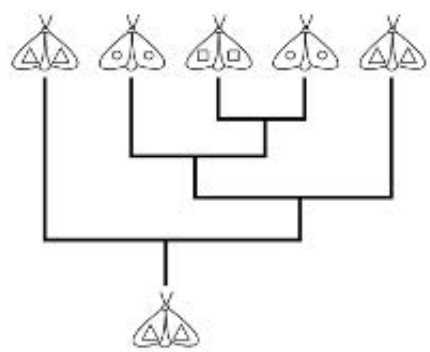


1. Draw a circle around all the animals alive today **that came from the branch with the star.**

   No guess (not sure)

2. Draw an X where the ancestor of lizards and mice, but NOT frogs, belongs.

   No guess (not sure)



3. Draw a circle around all the moths alive today.

   No guess (not sure)

4. Triangle wings changed to circle wings just once. Draw an X where this happened.

   No guess (not sure)

5. Draw a box around the moth that is the shared ancestor of the others in the diagram.

   No guess (not sure)

6. How confident do you feel about your answers to the questions in this quiz?

Very confident	Fairly confident	Not sure	Not too confident	Not confident at all

7. What kinds of information do you think these diagrams show?

Follow-Up Survey

VENOMVenture - Year 4 Summative Evaluation

Longitudinal Survey

Updated 9/22/2023

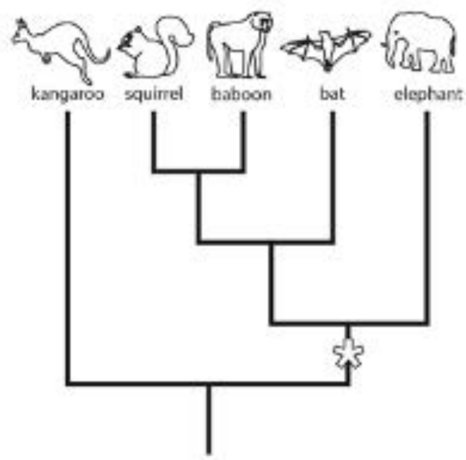
Thank you for taking our survey! Any member of your group who participated in the VENOMVenture game can fill out this survey. The more people who do it, the better! But please have each person take the survey just once.

First, how old are you? _____

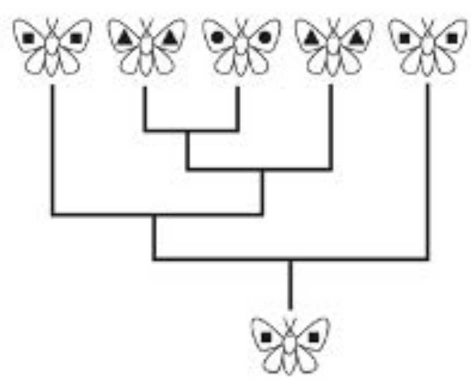
Your initials: _____

The questions below will check to see if you still remember some of the concepts from the game. We'll tell you how you did at the end of the survey!

Draw on the diagrams to answer the following items. If you are not sure about an item, it's ok to skip it and check "No guess (not sure)" instead.



1. Draw a circle around all the animals alive today **that came from the branch with the star**.
   - ☐ No guess (not sure)
2. Draw an X where the ancestor of squirrels and bats, but NOT elephants, belongs.
   - ☐ No guess (not sure)



3. Draw a circle around all the butterflies alive today.
   - ☐ No guess (not sure)
4. Square wings changed to triangle wings just once. Draw an X where this happened.
   - ☐ No guess (not sure)
5. Draw a box around the butterfly that is the shared ancestor of the others in the diagram.
   - ☐ No guess (not sure)

6. What kinds of information do you think these diagrams show?

7. How confident do you feel about your answers to this quiz?

Very confident	Fairly confident	Not sure	Not too confident	Not confident at all

After participating in VENOMventure, did you do any of the following things? (Check all that apply)

- Talk about the game days or weeks later
- Talk about the fun you had playing
- Talk about the design of the game (like the inflatable bus or the plants)
- Talk about some science concepts that were in the game
- Talk about medical or science careers related to the game
- Look up science or evolution information from the game
- Read the comic book from the game
- Do any of the comic book activities
- Explore any of the links from the email sent to you after the game
- Other (please describe): ________

[If they read comic book or did activities] When you read or did activities from the comic book, did you...?

- Learn more about science
- Learn about science careers
- Feel curious or interested in science topics
- Enjoy the comics or activities
- Other: _____
- None of these - I did not spend much time with the comic book.

[Adults only, and only if they explored links from email] Did the links from the email sent to you after the game help you or your child...

- Learn more about science
- Learn about science careers
- Feel curious or interested in science topics
- Enjoy the activities
- Other: _____
- N/A - We did not spend much time with the resources.

[Adults only] What do you think your group got out of playing this game?

- Positive experience working together
- Learned about science
- Had fun
- Enjoyed puzzles and problem solving
- Experienced a new way to learn science
- Other: ______

[Adults only] What do you think is the overall value of the VENOMventure game?

Observation Form

Venom Venture - Year 4 Summative Evaluation Observation Protocol *Updated 3/21/2023*

Time to complete game: ________

Puzzles completed in time limit: _____

Participant Group #: ___________

Date/Time: ___________________

Site: ________________________

Researcher: __________________

	Cephalopod	Dragon	Horse	Plant Matrix
Collaboration	☐ adult-led ☐ mostly adult ☐ equal ☐ mostly child ☐ child-led	☐ adult-led ☐ mostly adult ☐ equal ☐ mostly child ☐ child-led	☐ adult-led ☐ mostly adult ☐ equal ☐ mostly child ☐ child-led	☐ adult-led ☐ mostly adult ☐ equal ☐ mostly child ☐ child-led
Sensemaking				
Vocab	tree phylogeny branch lineage ancestor descendant evolve/evolution different traits trait changes over time variation in species TIME (old, modern, past, now)	tree phylogeny branch lineage ancestor descendant evolve/evolution different traits trait changes over time variation in species TIME (old, modern, past, now)	tree phylogeny branch lineage ancestor descendant evolve/evolution different traits trait changes over time variation in species TIME (old, modern, past, now)	tree phylogeny branch lineage ancestor descendant evolve/evolution different traits trait changes over time variation in species TIME (old, modern, past, now)
Solved	☐ on own ☐ w/ hint ☐ took answer ☐ by accident ☐ ran out of time	☐ on own ☐ w/ hint ☐ took answer ☐ by accident ☐ ran out of time	☐ on own ☐ w/ hint ☐ took answer ☐ by accident ☐ ran out of time	☐ on own ☐ w/ hint ☐ took answer ☐ by accident ☐ ran out of time

	Carnus Tree	Venom Tree	Anti-venom-o-matic
Collaboration	☐ adult-led ☐ mostly adult ☐ equal ☐ mostly child ☐ child-led	☐ adult-led ☐ mostly adult ☐ equal ☐ mostly child ☐ child-led	☐ adult-led ☐ mostly adult ☐ equal ☐ mostly child ☐ child-led
Sensemaking			
Vocab	tree phylogeny branch lineage ancestor descendant evolve/evolution different traits trait changes over time variation in species TIME (old, modern, past, now)	tree phylogeny branch lineage ancestor descendant evolve/evolution different traits trait changes over time variation in species TIME (old, modern, past, now)	tree phylogeny branch lineage ancestor descendant evolve/evolution different traits trait changes over time variation in species TIME (old, modern, past, now)
Solved	☐ on own ☐ w/ hint ☐ took answer ☐ by accident ☐ ran out of time	☐ on own ☐ w/ hint ☐ took answer ☐ by accident ☐ ran out of time	☐ on own ☐ w/ hint ☐ took answer ☐ by accident ☐ ran out of time

Post-Game Interview Protocol

VENOMventure!- Post-Game Debriefing/Interview Group #: __________

Year 4 Summative Evaluation

Congratulations on solving the game! Do you want to take a celebratory picture? [Hand them "we escaped" sign.] I'm going to give you a moment to take a rest and have a snack or a drink if you need one. While you do that, I'd love it if you could jot down some of your thoughts about the game on this paper/poster. [Give some time for families to fill out the paper on their own, and then ask them to talk about the things they've written, focusing on "I liked," "I learned," and "We did it!"]

❤️ **I Liked...** (What did you enjoy or What stood out to you?)

📚 **I Learned...** (What new information or skills did you get from this game?)

🌟 I Wish... (What could be added or changed to bring science alive for you and others?)

👥 **We did it!...** (Give an example of how you worked together.)

❓ I wonder... (Did this game make you think about something that you want to explore more?)

During this game, you had to interpret a lot of diagrams like these [show Carnus tree example]. What is this diagram showing you?

Did you learn this during the game, or did you already know it?

Where do you think the oldest plants on the diagram are? Where do you think the plants alive today are?

The branches split and form a tree shape. What do you think is happening at the splitting points?

What do you think these triangles are about?

Appendix B: Sample Sizes

Surveys – by Site

	Site	Pre-Surveys	Post-Surveys	Matched Pre/Post	Follow-up Survey
Phase 1	BPL	47	47	47	28
	CAS	40	39	39	12
	KUNH	43	43	43	18
	Modesto	41	41	41	9
Phase 1 Total		171	170	170	67
Phase 2	BPL	64	63	61	-
	CAS	66	65	64	-
	KUNH	123	123	121	-
	Modesto	33	33	33	-
Phase 2 Total		286	284	279	-
GRAND TOTAL		457	454	449	67

Surveys – Target Groups

	Pre-Surveys	Post-Surveys	Matched Pre/Post	Follow-up Survey
Younger children	56	56	53	4
Target group (children ages 9-13)	159	159	158	27
Older children and adults	240	238	237	35
Incomplete age data	2	1	1	1
Total	171	170	170	67

Appendix C: Additional Statistics

Performance on Individual Knowledge Quiz Items – Pre/Post Comparison

Q1 - Select animals alive today from the branch with the star			
Target Group (n=157)		Total Sample (n=446)	
Pre	0.694	Pre	0.712
Std Dev	0.461	Std Dev	0.455
Std Error	0.037	Std Error	0.022
Post	0.815	Post	0.821
Std Dev	0.527	Std Dev	0.437
Std Error	0.042	Std Error	0.021
P-Value	0.006	P-Value	< 0.001
Effect Size (Cohen's d)	0.221	Effect Size (Cohen's d)	0.200
Difference Between Averages	-0.120	Difference Between Averages	-0.110
Confidence Interval of Difference	-0.21 to -0.03	Confidence Interval of Difference	-0.16 to -0.06
t statistic	2.771	*t* statistic	4.233
Q2 - Ancestor of X and Y, but not Z			
Target Group (n=157)		Total Sample (n=446)	
Pre	0.580	Pre	0.582
Std Dev	0.494	Std Dev	0.494
Std Error	0.039	Std Error	0.023
Post	0.726	Post	0.729
Std Dev	0.571	Std Dev	0.496
Std Error	0.046	Std Error	0.023
P-Value	< 0.001	P-Value	< 0.001
Effect Size (Cohen's d)	0.265	Effect Size (Cohen's d)	0.317
Difference Between Averages	-0.150	Difference Between Averages	-0.150
Confidence Interval of Difference	-0.23 to -0.06	Confidence Interval of Difference	-0.19 to -0.10
t statistic	3.322	*t* statistic	6.690
Q3 - Circle all the animals alive today			
Target Group (n=157)		Total Sample (n=446)	
Pre	0.229	Pre	0.305
Std Dev	0.420	Std Dev	0.460
Std Error	0.034	Std Error	0.022
Post	0.567	Post	0.648
Std Dev	0.611	Std Dev	0.524
Std Error	0.049	Std Error	0.025
P-Value	< 0.001	P-Value	< 0.001

Effect Size (Cohen's d)	0.568	Effect Size (Cohen's d)	0.630
Difference Between Averages	-0.340	Difference Between Averages	-0.340
Confidence Interval of Difference	-0.43 to -0.24	Confidence Interval of Difference	-0.39 to -0.29
t statistic	7.117	*t* statistic	13.301
Q4 - Make an X where a trait change happened			
Target Group (n=157)		Total Sample (n=446)	
Pre	0.293	Pre	0.377
Std Dev	0.452	Std Dev	0.482
Std Error	0.036	Std Error	0.023
Post	0.479	Post	0.564
Std Dev	0.612	Std Dev	0.671
Std Error	0.049	Std Error	0.032
P-Value	< 0.001	P-Value	< 0.001
Effect Size (Cohen's d)	0.310	Effect Size (Cohen's d)	0.266
Difference Between Averages	0.190	Difference Between Averages	0.190
Confidence Interval of Difference	0.09 to 0.28	Confidence Interval of Difference	0.12 to 0.25
t statistic	3.884	*t* statistic	5.613
Q5 - Identify the shared ancestor			
Target Group (n=157)		Total Sample (n=446)	
Pre	0.360	Pre	0.438
Std Dev	0.478	Std Dev	0.496
Std Error	0.038	Std Error	0.023
Post	0.611	Post	0.675
Std Dev	0.611	Std Dev	0.652
Std Error	0.049	Std Error	0.031
P-Value	< 0.001	P-Value	< 0.001
Effect Size (Cohen's d)	0.406	Effect Size (Cohen's d)	0.352
Difference Between Averages	-0.250	Difference Between Averages	-0.240
Confidence Interval of Difference	-0.35 to -0.15	Confidence Interval of Difference	-0.3 to -0.17
t statistic	5.091	*t* statistic	7.437

Appendix D: Coding Open-Ended Responses

The pre/post/follow-up survey showed participants two evolutionary trees, and included the item "What kinds of information do you think these diagrams show?" This item was coded for correctness on a scale of 0 to 1 according to the following scheme. Each response received the highest correctness score below that it was eligible to receive; the scores are not additive. For example, a response that referenced both inheritance (a score of 0.5) and shared ancestry (a score of 1) would receive a total score of 1, not 1.5. Responses that did not fall into a category on this table were given a score of 0.

Table 4. Coding scheme for pre/post/follow-up survey item "What kinds of information do you think these diagrams show?"

Category description	Sample responses	Correctness score
Shared ancestry: indicates that multiple lineages share the same ancestor or that one ancestral lineages gives rise to multiple descendents	"Common ancestors of living species" "Evolutionary trees" "How traits are passed down through generations- different traits emerge from same ancestor" "These diagrams show a family tree"	1
Linear or unspecified ancestry: suggests that the diagrams show ancestors and descendents but does not clearly express the notion of shared ancestry	"Ancestors" "Evolutionary paths" "I think this information is graphing and looking at the chart and reading and the ancestors of the animals and insects" "It shows where or how ancestors work or time line"	0.75
Evolutionary change: references evolutionary or biological change to living things	"Evolution" "Evolution, biology" "How the animals have evolved"	0.75
Time: references history or time without connecting it to lineages or biological change	"History" "Why people know about animals' history" "History of the animals"	0.5
Inheritance: references DNA or genetics without connecting it to lineages or biological change	"I'm honestly not too sure but if I had to take a guess I'd say it's about genetics or something? I don't know." "Genetics"	0.5

In the interview, participants were shown the Carnus tree from the game and were asked "What is this diagram showing you?" Their responses were coded for what key ideas they mentioned. A single response could be coded for multiple categories if it mentioned several different key ideas. The set of categories that each response mentioned was then translated into a score of relevance to the diagram on a scale of 0 (no relevance) to 1 (the main thing the diagram shows) according to the following scheme. Each response received the highest relevance score value below that it was eligible to receive; the scores are not additive.

Table 5. **Coding scheme for interview item "What is this diagram showing you?"**

Category description	Sample responses (part of the answer related to corresponding category is underlined)	Relevance score
Shared ancestry: indicates that multiple lineages share the same ancestor or that one ancestral lineages gives rise to multiple descendents	"Evolution from the present day, <u>diverging of common paths</u>" "<u>How when the plant started and how it branched off into different species</u> and how it changed over time…"	1
Linear or unspecified ancestry: suggests that the diagrams show ancestors and descendents but does not clearly express the notion of shared ancestry	"<u>evolution from one species to another</u>" "I guess that's how scientists figure out diseases? They have to <u>go back to their ancestors to figure out where in that line</u> that problem thing developed that disease"	0.75
Evolution: uses the word evolve, evolution, change, or mutation	"<u>Evolution</u> from the present day, diverging of common paths"	0.75
Time: references history or time	"<u>Over time</u> the plants change to different warts, traits, etc. Like this plant had yellow and both of these had G"	0.5
Shared traits: refers to traits that different organisms have in common	"There's <u>one shared thing, that at least three of these have</u>, or two of these have, that was in the original ancestor. And so it changes, but there's still... it still kept something"	0.5
Traits: mentions characteristics of organisms generally or gives specific examples of traits	"Over time the plants change to <u>different warts, traits, etc. Like this plant had yellow and both of these had G</u>" "The genetic makeup of plants; <u>Traits</u> overtime"	0.25
Genetics: refers to DNA or genetics	"The <u>DNA</u>, which one has it, and which one doesn't."	0.25
Natural selection: references adaptation, natural selection, or survival of the fittest	"How things change, how they <u>adapt.</u>" "The evolution of how things change. Like they have to <u>adapt</u> to the things that are around them."	0
Environment: references the environment or habitat or organisms	"The evolution of how things change. Like they have to adapt to <u>the things that are around them</u>." "Ancestry, and how different kinds of plants spread off and got different kind of things based on their <u>habitat</u>."	0

In the interview, participants were shown the Carnus tree from the game and were asked "What do you think is happening at the splitting points?" Their responses were coded for what key ideas they mentioned. A single response could be coded for multiple categories if it mentioned several different key ideas. The set of categories that each response mentioned was then translated into a score of relevance to the splitting points on a scale of 0 (no relevance) to 1 (the main thing the diagram shows) according to the following scheme. Each response received the highest relevance score value below that it was eligible to receive; the scores are not additive.

Table 6. ***Coding scheme for interview item "What do you think is happening at the splitting points?"***

Category description	Sample responses (part of the answer related to corresponding category is underlined)	Relevance score
Speciation: refers to a lineage splitting into two	"If that didn't happen, there would just be one [species]" "One plant changes to make two different [ones]."	1
New species: refers to the idea of a new species starting	"They form a different plant" ""DNA change; creating different plants"	0.75
Evolution: uses the word evolve, evolution, change, or mutation	"Evolutionary change" "Evolving; having different traits" "The plants are going through changes"	0.5
Genetics: refers to DNA or genetics	"I don't know... the DNA changed? Something in their DNA changed. Why, I don't know." "The branches show the traits and passes on genes and DNA."	0.25
Babies: mentions offspring	"They had their own kids"	0.25
Traits: mentions characteristics of organisms generally or gives specific examples of traits	"Evolving; having different traits" "Something about the plant changes, like what it eats or what the leaves look like."	0

In the interview, participants were shown the Carnus tree from the game and were asked "What do you think these triangles are about?" Their responses were coded for what key ideas they mentioned. A single response could be coded for multiple categories if it mentioned several different key ideas. The set of categories that each response mentioned was then translated into a score of relevance to the triangles on a scale of 0 (no relevance) to 1 (the main thing the diagram shows) according to the following scheme. Each response received the highest relevance score value below that it was eligible to receive; the scores are not additive.

Table 7. ***Coding scheme for interview item "What do you think these triangles are about?"***

Category description	Sample responses (part of the answer related to corresponding category is underlined)	Relevance score
Evolution: uses the word evolve, evolution, change, or mutation	"It's what's changing" "Changes and DNA" "Trait changes"	1

Timing: suggests that the triangle indicates when something happened	"Shows the evolution, which changed happened when." "When the traits change"	0.5
Traits: mentions characteristics of organisms generally or gives specific examples of traits	"Trait changes" "It shows which changes happened, like the warts go from purple to yellow. The plant changes and a new species starts."	0.5
Linear or unspecified ancestry: suggests that the diagrams show ancestors and descendents but does not clearly express the notion of shared ancestry	"What they used to be and how they changed into" "Different variants evolve into modern day" "This is like a chain and there are changes happening…"	0.25
Genetics: refers to DNA or genetics	"Changes and DNA" "Slightly different DNA and genetics."	0.25