
Zoombinis and the Art of Mathematical Play

by Chris Hancock and Scot Osterweil

Play is nature's greatest educational device. During play, children routinely exhibit the inventiveness, experimentation, and enjoyment of thinking that sometimes seem so sorely lacking in schools. For mathematical play, computers are an especially appropriate medium because they allow players to project themselves imaginatively into worlds that embody powerful mathematical ideas. The great promise of computer games is that they might harness the power of play and computers to help more children learn more math.

Despite this promise, most of today's computer math games perpetuate an impoverished view of mathematics and of learning. Many games are essentially drill-and-practice programs that focus on a narrow set of skills and rely on arcade-style effects, hand-eye coordination, and time pressure for entertainment value. They treat the playful elements as something distinct from the mathematics, which too often is portrayed with little imagination or enthusiasm.

Still, while good math games may not be common, we are confident that they are possible. In working with Brøderbund Software to design the newly released game Logical Journey of the Zoombinis, we have gained a clearer sense of what it takes to make a good math game.

Logical Journey of the Zoombinis grew out of several years' work at TERC researching and developing computer-based tools that support the trend toward increased emphasis on data, graphing, and statistics in classrooms. In the course of designing and testing these tools, we uncovered a rich network of mathematical ideas with which children work to understand data and representations of data. This "mathematics of data" begins with sorting and classifying activities common in primary grades and grows to include attributes, logic, combinations, arrangements, and graphing, with connections to algebra and functions as well. We experimented with a variety of visual approaches that might help to make these topics accessible, interesting, and fun: this led us to the Zoombinis.

Meet the Zoombinis

Of the many objects and characters that we designed, the Zoombinis -- small blue creatures with no bodies distinct from their heads -- revealed a special ability to bridge mathematics and children's imaginations.

As mathematical objects, the Zoombinis embody the powerful ideas of attributes and combinations. Each Zoombini may have one of five kinds of hair styles, eyes or eye wear, nose colors, and feet or footwear. Thus there is the possibility of forming 625 different combinations. In its mathematical structure a Zoombini is similar to a record in a database, a base-5 number, and other mathematical objects such as vectors. Zoombinis can therefore take part in many mathematical processes related to data analysis, graphing, algebra, and logic.

The player recruits five possible traits for each of four attributes.

But a Zoombini is more than just a mathematical object. We began to understand this when we first put paper Zoombini cut-outs in children's hands. We were struck by the children's continuing fascination with these creatures. Children drew Zoombinis, made their own cut-outs, and created stories around their different Zoombinis. Days later they were still engrossed.

What is the source of this appeal? Part of the pleasure of making lots of Zoombinis is experiencing the mathematical power of combinations. Children see how a small set of features can be mixed and matched to make an astounding variety of individuals. It is like learning a new language and delighting in how many things one can say. The Zoombinis are also attractive and easy to identify with. They have an understated quality which makes it possible to imagine many different personalities for them. Some of their features are unusual and intriguing (imagine having wheels or propellers for feet); others, like hair styles, sneakers and roller skates, represent features that can be parts of children's own self-image. In the Zoombinis the abstract power of combinations becomes a discovery about the wide range of possibilities for picking and choosing the features of oneself. The Zoombinis are mathematics made personal.

We, like the children, were stimulated to create personalities for the Zoombinis. We envisioned them as social creatures that are tolerant of their differences. Although small and innocent, they are hardy, resourceful, and surprisingly good at overcoming difficulties. These qualities (in the Zoombinis, and in the game player) are put to the test in the epic story of the Zoombinis' journey.

The Zoombinis' Journey

In Logical Journey of the Zoombinis, the Zoombinis' island home has been taken over by ogres, and they must flee to found a new town in a distant land. Traveling in small bands, they encounter obstacles, each of which embodies a mathematical problem. In Figure 1, for example, the Zoombinis have been blocked by trolls who insist on being fed pizza before they will let the travelers pass. Each troll is very particular about the pizza it wants, but communicates only by reacting to pizzas that the Zoombinis offer: either "There's something on that I hate!" or "I want more toppings!" From these clues, the player must deduce what toppings each troll wants, and build the appropriate pizzas to satisfy them.

Figure 1. Pizza trolls provide clues to the toppings they want. (larger image)

In Figure 2, an underground stretch of the journey brings the Zoombinis to a cavern where a huge stone lion blocks the path. Controlled by a mysterious ancient technology, it will move its paw once the Zoombinis are lined up in order. Any of the Zoombinis' attributes might be the basis for the ordering that the lion requires. Each Zoombini that is placed yields more clues, but too many wrong placements will bring down the gate, forcing the group to leave some members behind temporarily.

Figure 2. The Zoombinis must sort themselves by eye type in order to pass through the lion's lair. (larger image)

In all, there are twelve such puzzles. As successive bands of Zoombinis pass through, the player has the opportunity to play each puzzle many times. Each time, the puzzle is reconfigured to require a different solution. As the player becomes more effective at getting the Zoombinis through, the puzzles also progress through four levels of difficulty.

Mathematical Content and Mathematical Thinking

The puzzles in the game are organized in four paths traveled by the Zoombinis. Within each path the puzzles develop a group of related mathematical ideas: sets and logical relationships; dimensions, graphing, and mappings; local relationships and strategic searching; and a mixture of sorting, comparing, algebra, and algorithms. These topics are the math of the information age: the math our children will use in organizing data, programming computers, and searching for information on networks. The ideas range from the most basic principles of logical thinking which children begin to learn around age 4, to topics which are taught formally in college. All are developed in the context of the attributes of Zoombinis and other attribute-based characters and props.

Mathematics is a system of concepts and topics, but it is also a set of habits of mind, and ways of approaching problems. The puzzles in Zoombinis call on mathematical thinking processes such as looking for patterns, organizing information, reasoning about evidence, and systematic testing. When a player initially encounters a puzzle there are no instructions: just a challenging obstacle (a pizza troll, a ferryman, a machine) that is behaving in its own peculiar way. Only by looking for patterns in this behavior can the player develop a sense of what the problem is, let alone how to solve it. In real life, where problems tend not to come pre-packaged with instructions about what math to use, this kind of pattern-finding is important.

Sometimes the key to solving a math problem is finding the best way to organize the available information. In Zoombinis, this generally means organizing one's Zoombinis according to traits or combinations of traits. The player who takes the initiative to do this will find many puzzles easier to think about.

Reasoning about evidence is an essential part of successful gameplay. In most puzzles the player will make a number of "wrong" guesses, but these provide the very evidence needed to solve the puzzle. If one choice didn't work, are there other choices that can also be eliminated? What other choices might still be valid? In the game, as in mathematical problem solving and as in life, you

can gather useful information from all your efforts, whether or not you meet with immediate success.
Finally, systematic testing is often essential to solving the puzzles. If you learned something from one action, what next step will be most effective in confirming or expanding upon that information? Because you sometimes run out of tries, the game will reward the player who has an efficient strategy for narrowing down the possibilities.

Principles of Game Design

In the course of developing Zoombinis we began to clarify for ourselves some important principles in designing a high-quality math game that respects and engages children's own imagination, intelligence, and initiative. These principles reflect our experience in educational design, our observations of children playing, and our underlying philosophy of learning and play.

Putting the Learner in Charge

A "learner-centered" game gives children freedom to play and challenge themselves in their own way. The child can choose different parts of the game at different times, and define success on her own terms. This flexibility reflects the belief that deep learning cannot be imposed from without, but depends on the child's interest and initiative. It also reflects a basic faith in children's minds, and in the principle that children naturally seek out and engage with new ideas when they are ready to learn them.

Integrating Mathematics, Stories, and "Rewards"

We want to present mathematics not as a sterile, disconnected endeavor, but rather as a set of patterns and principles that can help us make sense of situations. A story context can help make the pieces of a puzzle more interesting, and more accessible.

Integrating mathematics and story also allows an integrated approach to the rewards of gameplay. In educational software jargon, a "reward sequence" is an animated effect that is used by the game to reward the player for accomplishing some task. While we don't object to feedback that helps players note their successes, we want to support children's experience of mathematical thinking and insight as enjoyable in its own right. The best game problems are inherently rewarding to solve.

Depth

Designing for depth means: developing underlying concepts and ideas, rather than superficial procedures; making the game accessible and interesting to as wide a range of players as possible; providing a smooth ramp of difficulty that players can progress along; and giving players the opportunity to pursue their interest to an advanced level.

The principle of mathematical depth opposes the excessive stratification of our mathematical society: the ideas that six-year-olds, twelve-year-olds, parents, and professors grapple with are not as far apart as is often assumed. We have observed families, including our own, in which children and parents all enjoy playing Zoombinis at their own levels, and this in turn leads to far more family "math talk" than if the game targeted a narrow age group.

Coherence
Many popular math programs provide a grab-bag of activities -- a little arithmetic, a little geometry, some attribute math. While the individual components may be interesting, they do little to support each other. But to develop an idea well, and to make it accessible to more people, it is important to come at it from a variety of directions. Some children will initially favor one approach or another, but eventually all the approaches can be combined in a well-rounded mastery of the game. Zoombinis features clusters of puzzles which develop a common main idea (e.g. multidimensional arrangements, or sets and logic), and these clusters are in turn interconnected by a web of common themes and ideas.

Where do Good Games Come From?

It was only after developing this list of design principles that we noticed that few math games on the market embody all of them to a significant degree. Are we asking too much to hope for such games? How do really good math games come into being?

There is a paradox in the idea of designing a game with educational goals. The essence of play is that it is done for its own sake -- any utilitarian purpose which we might attribute to play is not of concern to the person doing the playing. On the other hand, the traditional forms and activities of school mathematics have evolved as work, not play. It's fine to expect kids to do work, but not during the spare time that they spend playing games. Does this mean that our goal should be to bribe children with reward sequences, or trick them into learning when they think they are playing? Even if we can fool some kids some of the time, over the long term these approaches will work against children's building a lasting positive relationship with mathematics.

The case of Zoombinis suggests an alternative. In our investigations of children's understanding of the mathematics of data, we identified ideas that were particularly interesting or empowering to children, and watched where they spontaneously made mathematical games and challenges for themselves. Interwoven with this process was our own deepening understanding and enjoyment of this branch of mathematics. Taking cues from children's aesthetics as well as our own, in effect we found the "game in the math" rather than putting math in a game. And, almost by necessity, the math looks different from how it does in a classroom.

So here, perhaps, is a more promising solution to the paradox of educational games: authentic learning and authentic fun can come together in games that reflect the game maker's own love of the material, combined with a knowledge of children's thinking and aesthetics. Many youngsters have helped us to find delight in the mathematics of data. We hope that Zoombinis will spark that pleasure in many more.

Authors

Chris Hancock and Scot Osterweil are co-designers of Logical Journey of the Zoombinis.
Chris_Hancock@terc.edu; Scot_Osterweil@terc.edu

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Logical Journey of the Zoombinis ordering information

The computer game is available from retail stores and from Brøderbund Software, 500 Redwood Boulevard, Novato, CA 94948-6121, 1-800-474-8840.

TERC has also developed complementary classroom software: Tabletop Jr., an exploratory environment for the mathematics of data K-4; and Tabletop, a tool for graphing and data analysis, 4-12. Both are available from Brøderbund Software.

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