Games for the Science Classroom

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I have always found biology fascinating. The science of life itself is magical – how a single cell forms an entire human being, how bees communicate, how a plant responds to sunlight. In 2016, in a bid to inspire others to study biology, I decided to teach *evolution* to students of Shri Devi Sateri High School – a school in rural Sindhudurg (Maharashtra), close to my native village. I have always felt that the approach of teaching theory in classroom sessions is ineffective. Not only is it difficult to keep students engaged but presenting biology as a string-of-facts precludes an appreciation of the complex cellular and molecular phenomena which drive biological processes. This is true not just of teaching *evolution*. Biology is generally taught as a set of lectures or experiments. But traditional biological experiments require relatively costly infrastructure and training, which might not always be available in rural schools. The third option was gamification – a fantastic way of engaging young children while teaching scientific concepts. Games allow children to experience shared learning, exploring and deriving scientific principles for themselves. I, therefore, searched for biology-based games or activities – but found only games based on physics or chemistry. This set me on a path to gamifying biology. Having no prior experience in creating games, I first laid down the principles that the games should espouse.

Starting out

I found a few biology-based activities that helped me begin. One example is teaching parameters that control cell size. Cell size depends on many factors, but one key limitation is the time taken by nutrients to travel from the cell surface to target organelles. If the nutrient does not reach the target within time, the cell may die. One way for nutrients to travel is diffusion. A simple way to replicate this in a laboratory is by using agarose cubes of different sizes, infused with a pH indicator. These pieces when put in acid change colour in response to the pH change. The larger the piece, the longer it takes for the colour change to reach the core. One can simply have students make agarose of different sizes and once the pieces are ready, have a race to see whose piece completes the colour change first. This is a fantastic activity to reinforce two things: one, unlike shown in textbooks, cells are actually three-dimensional and second, the larger the cell, the more time nutrients take to travel within it. Since a number of molecular reactions within the cell are time-dependent, cell size has to be configured to optimise nutrient transfer. In schools where resources for creating agarose pieces might not be available, similar experiments can be performed using pieces of beetroot or bundles of chromatography paper.

I tried this activity with a few students and their reaction demonstrated the benefit of transforming principles into activities. They had fun while making these agarose pieces; they were awed by the changing colours and triumphant as they understood how this simple activity is related to one of the core phenomena in biology. In doing this experiment, I found the principles I would use for gamifying biology.

Principles for gamification

Games should teach core principles

> An important facet of gamification is the intended outcome. Do you want the students to learn a fact or a principle? While games can be based on either, my drive behind gamification was to communicate basic principles, which the students could then apply to biological phenomenon. Distilling down a biological concept to its basic principles helps refine the design and rules of the game.

The cell size activity, for example, does not directly involve studying cell size. Instead, it teaches the relation between size and diffusion and this core principle can then be applied in the context of cell size. This makes the activity less daunting and once the core principle is learnt, it can be applied across multiple phenomena.

Games are about shared learning and exploration

A core tenet of games is shared learning – participants work together as they try to solve a

puzzle, break a code or trace a path out of a maze. During this time, they are learning from their own mistakes or successes as well as from their peers. Games should allow for this learning and have time built in to reflect on this learning after the game is over.

In the cell size activity, some students will invariably make a huge piece of agarose and learn that a bigger size does not help them win the eventual race. This shared learning helps the entire class learn and remember the principles.

Games should be fun

While the primary objective of a game should be learning biology, an important outcome is the built-in opportunities to have fun. This could be in the form of a group or individual activity – such as racing, drawing or another game, like dumb charades. When participants have fun, they can connect back to the learning experience.

For the cell size activity, the fun is in thinking about what the shape and size of the agarose pieces should be. Students can do this individually or in groups and pour their creativity into making the pieces. Even if not all students remember the principle of diffusion, most of them will remember the fun in making a star shape or sphere out of agarose.

Games should be flexible

Not all schools will have similar physical infrastructure and even within the same school, the modalities of the game will differ depending on the strength and grade of the target class. Therefore, it is important to build flexibility into the game, allowing for its use to be tailored by the teacher, depending on the learning level of the class.

The cell size game can be played in most schools and is flexible to be re-imagined using the resources available there. The important point of the game is figuring out the core principle to be taught and a mechanism to gamify it. Once that mechanism is understood, a teacher could use the tools at their disposal to re-invent the game for their students.

Students should be central to the game

Games have to be optimised to ensure students can get the most fun and learning out of playing. This approach can challenge traditional concepts of game design, but it is important to prioritise students' experience over trying to fit the game into a traditional design.

The cell size game is all about students having fun and being creative. It is about giving them the space to create something with their own hands and learning from it. Once they have fun in the activity, they are more likely to remember both the game and the principle.

Approach to game creation

With these core principles in mind, I set about creating a game based on the principles underlying evolution. There are various ways to gamify – you can create an activity-based game (like the cell size one), a card game or a board game. Since evolution works across time, I thought a board game depicting the passage of time would be an ideal start. Thus, each block on the board would correspond to a unit of time, and with each move, the participant would move forward in time.

The next step was to identify the core principles that I wanted to teach through the game. I narrowed down on the following principles:

1. Pressures from the environment affect the characteristics of species; thus, species gain traits to adapt to the environment.
2. For evolution to happen, the changes have to occur at the species level.
3. Evolution is a continuous process.
4. Organisms/species that cannot adapt to their environment, eventually, die out.

The next step was to design the game. Traditionally, board games involve a small board, pawns and cues. My first thought was to create animal/tree-based pawns that individual students could play with. While this sounded like a good idea, it did not seem to be the best way to keep the student at the centre of the game. This board game would cater to only five-six players at a single time and it would be difficult to keep them engaged. I, therefore, decided to flip the idea of a traditional board game – making the students into pawns themselves and turning the classroom into a giant board. This meant we could now play with a class of 30-35 students and all students would stay engaged with the game.

The core process of the game would be to have students play various species going through time, giving them specific selection pressures and a chance to adapt and awarding points on traits gained and members of species surviving at the end.

This was the start of the idea – the board could be drawn on the ground of the classroom or play

area. Some teachers used chalk, some created flex boards, some had their common-room floors painted to incorporate the board. The students were to be divided into teams of five and asked to randomly pick three characteristics – flight, burrowing, swimming, etc. Some teachers created props for the students to engage them further. One representative from each group would stand on the board while the other members sat in a group next to the board, cheering on their representative. The board depicted the passage of time and was randomly strewn with challenges. Each challenge was a selection pressure – a flood, a volcano, a new disease. In some places, we used dice to dictate movement across the board, like traditional board games. One innovative teacher used this idea to create a dial, marking time. The students would spin the dial to figure out how many spaces across the board they could move.

The challenges were marked by numbers on the board. If the group landed on a challenge, the teacher used 'challenges cues' to assign a challenge. If the group had a trait that could help it deal with the challenge, the group was safe. For example, if the challenge was a flood, but the group could swim, they were safe. If they did not have a compatible trait, the group would be given a chance to adapt by playing an activity. The challenges were also designed to be fun and flexible. For example, if the challenge was a flood, the activity to gain a trait was jumping across a make-believe pond. Some teachers asked the students to use white and blue chalk to mark a pond on the floor, some used a piece of blue cloth. The size of the 'pond' depended on the age of the students. Those who fell in the pond were out of the game, those who passed were deemed to have adapted to the challenge and gained a trait.

The game was designed to allow teachers to figure out challenges and activities on their own, depending on the age of the students, size of class and resources available. The challenges could be based on a regular school curriculum or to capture a current event, such as a pandemic. The activities can range from pin the tail of a donkey to a three-legged race, depending on the class. This flexibility again centralises the students, focussing on them having fun while learning.

The game starts with four or five competing species. Points are given based on new traits earned and for surviving members of the species. The game usually lasts for 30-45 minutes. At the end of the game, the students are asked what they learnt from the game. The first time I did this exercise with the students of Shri Devi Sateri High School, I was impressed with their responses. One student said, 'When you face challenges, you can find a way to overcome them.' Another said, 'For the same challenge, there are multiple ways to overcome it.' This is true of evolution as well, and something I had not even included in the design of the game!

We then talked through the major principles we learnt. Every time a team overcame a challenge, they won a trait and could move to the next round. Adaptation through adjusting to environmental pressures is a key tenet of evolution. The board is littered with challenges – evolution is a continuous process and species are always responding to environmental pressures. Those who fail at a challenge, 'die' out – indicating that species that fail to adapt, become extinct. At the end of the game, the team with the most traits and surviving members wins – this conveys that a single member of a species getting adapted does not mean that the species is safe. Evolution occurs at a species or population level, not at the individual level. Once we go through these principles, the students are invited to think about their favourite plant or animal species and talk about the traits which they think have helped the species to adapt to their environment. This cements the principles to the broader concept and reinforces the learning by relating the concept to personal experiences or likes.

All elements of the game are printable; if a printer is not available, these can be drawn on paper or board. This makes the game freely available to all and customisable.

There are limitations to the game that also need to be discussed. No species can easily pick up traits – a fish cannot also have wings. While this reality is suspended in the simpler versions of the game, there is a way to include this in subsequent iterations as students learn. In subsequent versions, traits can be given points and a group can only have a fixed upper limit of points. Thus, if they want to take in a new trait to adapt, but that trait increases the total points they have over the fixed limit, they will have to trade in a trait that they already have. This also mimics evolutionary principles to a certain degree. The game can also be designed to include overlapping pathways, allowing species to cross paths and predate on each other. Once the principles and objectives of the game are clear, the teacher can add elements based on her discretion. The mathematics teachers at Shri Devi Sateri High

School used this game concept to create a similar game for teaching maths and the new GST rules which had just come in.

Another key point is that these games can also be made virtual – but that can distract from the shared learning and physical experience of playing. Hence, I make a conscious effort to make board or card games, and not virtual games. However, virtual games might be attractive to a target audience and the same principles could be used to create a virtual evolution game.

Conclusion

The evolution game has now been tried across multiple schools and grades – including the Agastya International Foundation, Bengaluru – and has been welcomed as an addition by the teachers. Creating games based on biology is simple: focus on the underlying principles, not on the biological facts that are to be taught. The principles can be adapted to become the rules of the game. Find the way in which the students have the most fun and are most engaged while playing the game. Keep an open mind in game design and do not be limited by traditional concepts of games. It is best to keep the game tiered so that the increasingly complex concepts can be taught over time. Ensure there is reflection time for the students to go through the principles they have learnt and can apply them to biological concepts on their own. Games are a great, fun way to teach biology, particularly in contexts where resources for high-end experimentation might not be available.

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