ARTICLE
Teaching Principles of an Action Potential Using Candy

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Neurophysiology is crucial but often-intimidating subject for undergraduate students. To address the challenge of "neurophobia" educators have developed myriad techniques to inspire students and enhance their interest in the discipline. We therefore sought employ one such innovation to further engage our students, leveraging students' familiarity with food to make the abstract concept of the action potential accessible.

Seventy-seven Foundation Year students undertook a 60-minute in-person didactic lecture and then a two-hour active learning class using Smarties and Play-Doh to make a detailed model of an action potential and its constituent phases. They were given a post-activity five-point Likert questionnaire with four open-ended questions, and responses were analyzed with a weighted average ($\bar{x}_w$).

Broadly, students enjoyed the playfulness of the activity and agreed that they would like to repeat it. Respondents did not agree that the activity *per se* motivated them, but they agreed that the activity improved their knowledge of action potentials, felt the format was appropriate to check their knowledge, and felt that it helped identify weaknesses in their understanding. Students felt they were able to connect with their team during the activity, that they learned from their teammates during the activity, and teamwork as a positive was a repeated theme in the open answer questions.

Using Smarties to teach action potentials is a fun and effective way to teach neurophysiology and further research is required to determine its impact on student attainment.

Key words: action potential; edible science; physiology; pedagogy; innovations in teaching

Neurophysiology is a crucial yet often intimidating subject within the undergraduate biosciences curriculum, a challenge often referred to as "neurophobia" (Jozefowicz, 1994). To address this challenge, educators have developed various pedagogical techniques to enhance student interest in neurophysiology, including interactive simulations, puzzles, worksheets, and YouTube videos (Boardworks Education, 2024; TES, 2024). However, there remains a need for additional methods to further engage students with this complex topic as all too often, educators resort to presenting information in graphical and mathematical forms long disliked by generations of students (Michael, 2007).

As biology lecturers, we are encouraged to make our subject matter more engaging and accessible (Rutherford and Ahlgren, 1991). This is especially important for those who may struggle to grasp basic concepts in neurophysiology, whether due to their inexperience with the subject or initial anxieties. One innovative approach to spark interest in neurophysiology is by leveraging students' familiarity with food.

Edible science is an innovative teaching method that uses food to make abstract neurophysiology concepts, like the action potential, more relatable. By employing food as a tangible analogy, students can better grasp the complex process of how nerve impulses travel (Çömek et al., 2016). This approach engages multiple learning preferences—kinesthetic, visual, and interpersonal—making it particularly effective for non-traditional learners who benefit from hands-on and interactive experiences (Francek and Winstanley, 2004). Additionally, edible science is personally satisfying, as students may wish to consume the results of their activity, making it more memorable (Piqueras-Fiszman and Jaeger, 2016).

Given that student engagement increases under emotional arousal (Dolcos et al., 2004), there is a compelling argument for creating activities that enhance happiness and creativity. One such engaging activity involves the use of Smarties, a popular confectionery, to model the action potential in neurophysiology. While Smarties have been used in other educational settings, such as teaching data analysis to primary level maths (students are aged between 4-11 in the UK) to help students grasp physics concepts, there is limited literature on their use in biological education (TES, 2024; Hart, 2008). This paper presents a low-cost, flipped classroom exercise where students work in teams to model an action potential using Smarties, and then present their findings using neuroanatomical terminology. The aims of this activity were to: 1) provide students with practice in modelling the action potential using 3D structures, and 2) enhance their ability to use anatomical and physiological terminology. More broadly, this activity seeks to increase student engagement and confidence in learning neurophysiology.

MATERIALS AND METHODS
Activity
This study was conducted with Bioscience Foundation Year students at the University of Surrey (A Foundation Year is a year-long program of preparatory study, and upon completion, may provide a pathway into an undergraduate

degree program). Seventy-seven foundation students undertook the activity. Traditionally, the nervous system module for Foundation Years, consisted of the following topics delivered through lectures: 1) nervous system structure 2) structure of nerves 3) resting and action potentials 4) refractory period 5) synapses and their functions 6) neurotransmitters. Students would be expected to recall their knowledge through an end-of-year short answer question exam and multiple-choice exam.

In this activity, all students were taught about the mechanism of how an action potential moves along a neuron in a 60-minute lecture in person. The week after the lecture, the students attended a two-hour active learning class using Smarties and Play-Doh to consolidate knowledge they had been previously taught. Students were first put into groups of two and each group were provided with A3 paper, coloring pencils, smarties, dairy milk buttons and Play-Doh. Students were expected to make a 3D model of how an action potential is propagated along a neuron under three stages: 1) Resting potential 2) Action potential 3) Repolarization (Figure 1). Students were under the supervision and guidance of an academic; they were allowed to review their class notes and lecture slides to guide them in the modelling process.

The models had specific requirements and students were expected to use the resources they had been provided with to represent a particular component within the process. For example, students were expected to choose two colors of smarties, one to represent sodium ions and another to represent potassium ions. Each stage (resting potential, action potential, repolarization) had to include the distribution of sodium (Na^+) and potassium (K^+) ions across the axon, the role of sodium-potassium pump, and the state of voltage-gated channels (open or closed). Additionally, the models needed to reflect the voltage readings at each stage, highlighting the shifts in electrical charge within the axon.

After finishing the task, students were asked to demonstrate and explain how a nerve impulse moves along a neuron to the academic by moving the smarties that represented the ions and discussing what happens in each stage. Their ability to model and discuss each stage, comprised their assessment for this part of the class.

Analysis

Students were given a post-activity questionnaire (Manzano-León et al., 2021) immediately after completing the activity in March 2023, consisting of sixteen questions addressed via a five-point Likert Scale from 1 (Strongly Disagree) through 3 (Neither Agree nor Disagree) to 5 (Strongly Agree) as follows:

Following your participation in this learning activity, to what extent do you agree with the following statements?

In general, I have enjoyed this playful activity
I would repeat these types of activities
I have felt motivated
I improved my knowledge of the subject
My interest in the subject has increased
This activity format has been appropriate to check my knowledge of the subject
This activity format has helped me identify my weaknesses in the subject
It helped me understand the content of the subject
With these types of activities, I learn more
I feel like I was able to connect with my teammates to learn
I learned from my classmates during the activity
I found the game elements fun
The game elements have motivated me to carry out the activity
While playing I was not aware of what was happening around me
I felt capable of carrying out the proposed activities
I found the activities comforting and valuable to me

There were then four questions addressed by open answer as follows:

Were there any obstacles with participating in the activity? If yes, what were these?
In your view what worked well with the activity?
In your view what could be improved with the activity?

Data were collated and responses logged from 1 to 5 for statistical analysis, while responses for each question were calculated as a percentage. Open ended questions were analyzed for repeated themes and presented as direct quotes for enrichment of discussion.

Ethical Considerations

A member of the research team communicated the objectives of the questionnaire, the confidentiality of information provided and ethical considerations to the prospective participants. All participants were provided with an information sheet and informed consent was required, prior to starting the questionnaire. Approval for administration of this survey was obtained from the University of Surrey ethics Committee (FHMS 21-22 264).

Statistical analysis

Data were analyzed in IBM SPSS Statistics (SPSS) version 29.0.1.0 (IBM, NY, USA) to calculate mean, standard deviation (STDEV) median, mode of each question.
Weighted average ($\bar{x}_w$) was calculated as follows:

$$\bar{x}_w = \frac{\Sigma\bar{x}}{\Sigma L}$$

Where $\Sigma\bar{x}$ is the sum of the mean score (1-5) of each Likert question and ΣL is the total number of Likert questions, i.e., 16. A mean percentage score (see Table 1) of respondents greater than the x̄w was then set as a threshold for a positive perception to the Likert question (Alonazi et al., 2019; León-Mantero et al., 2020; Fall and Surendran, 2023).

RESULTS

Quantitative Analysis

There was a potential population of 77 students, and 25 responses to the questionnaire, giving a response rate of 32%, which is broadly in line with acceptable response rates in pedagogical research (Nulty, 2008). This resulted in a weighted mean $\bar{x}_w$ of 3.92. Therefore, a $\bar{x}_w$ of 3.92 and above was considered a positive response. The full results are presented in Table 1.

In summary, the students felt capable of carrying out the task, they appeared to enjoy the playfulness of the activity, found the game element fun, felt their knowledge of action potentials and the overall subject area improved, and felt that they would like to repeat the activity. They also felt that it was an appropriate activity to check their knowledge of the subject, to identify weaknesses, and there was a broadly positive response to the teamwork involved. Importantly, not a single respondent would prefer not to repeat the activity.

The students didn't feel motivated *per se* by the activity (Figure 2), they didn't feel they were able to lose themselves in the activity, and the activity didn't increase their interest in the topic.

Qualitative Analysis

The short answer, open-ended questions elucidated several key themes. There was a continued theme of teamwork being something that worked well, with eight respondents specifically referencing it in their short answer responses.

For example:

Teamworking skills increased among teammates
Reinforced knowledge multiple times during lesson
Able to identify areas of weakness while it not feeling pressured
Working in the teams to complete the task
It combines teamwork with application of knowledge

Of those not specifically mentioning teamwork, there was a recurring theme of the activity working well because it specifically allowed the respondents to visualize the events in the membrane during an action potential. For example:

How we could visualize the membrane and how ions moved to create an action potential
It still tested my knowledge on the subject and was a great visualizer of the several processes within
Working in pairs and modelling the process in a visual way

There was also a recurring theme of the respondents enjoying the creativity aspect of the activity. For example:

it was engaging and wasn't just staring at a screen and writing notes
The activeness and freedom to be as creative as we like.
Making our own moulds (sic)
Creative and interactive.

When asked what could have been improved, there was no real recurring theme that emerged. The only duplicated comment (n=2) was that larger group sizes could be considered in future.

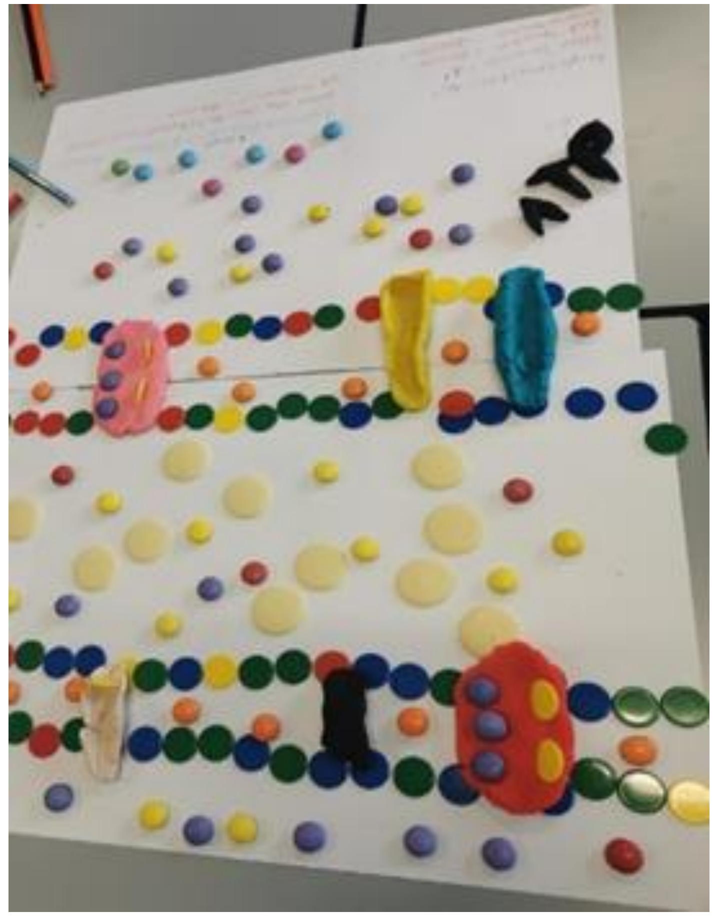

Figure 1. An action potential model created by a respondent

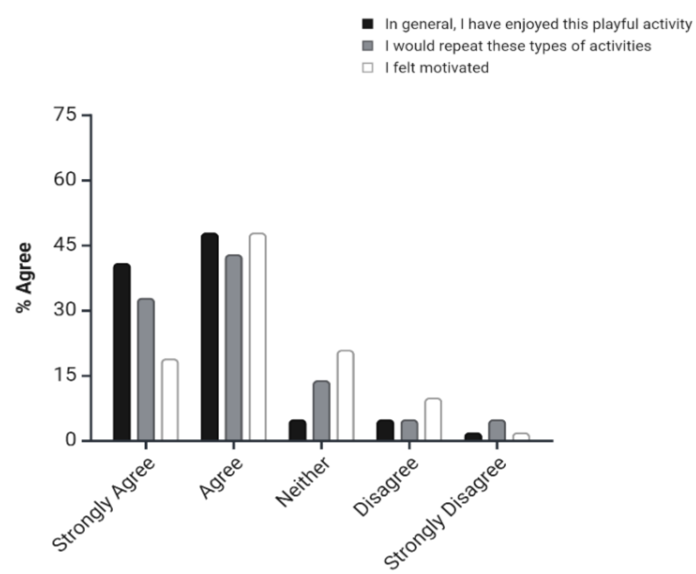

Figure 2. Responses regarding student enjoyment and motivation of the activity

	%SA	%A	%N	%D	%SD	$\bar{x}$	M	Mo	Decision
In general, I have enjoyed this playful activity	28	68	4	0	0	4.24	4	4	Positive
I would repeat these types of activities	24	64	12	0	0	4.12	4	4	Positive
I felt motivated	20	52	24	4	0	3.88	4	4	Negative
I improved my knowledge of the subject	24	48	24	4	0	3.92	4	4	Positive
My interest in the subject has increased	12	36	44	8	0	3.52	3	3	Negative
This activity format has been appropriate to check my knowledge of the subject	24	72	4	0	0	4.2	4	4	Positive
This activity helped me identify my weaknesses in the subject	28	48	20	4	0	4	4	4	Positive
It helped me understand the content of the subject	20	60	16	4	0	3.96	4	4	Positive
With these types of activities, I learn more than in traditional classes	8	36	28	28	0	3.24	3	4	Negative
I feel like I was able to connect with my teammates to learn	16	76	8	0	0	4.08	4	4	Positive
I learned from my classmates during the activity	16	64	12	8	0	3.88	4	4	Negative
I found the game elements fun	32	68	0	0	0	4.32	4	4	Positive
The game elements have motivated me to carry out the activity	20	60	16	4	0	3.96	4	4	Positive
While playing I was not aware of what was happening around me	8	40	12	32	8	3.08	3	4	Negative
I felt capable of carrying out the proposed activities	36	60	4	0	0	4.32	4	4	Positive
I found the activities comforting and valuable to me	28	48	20	4	0	4	4	4	Positive

Table 1: Responses to student perceptions of a gamified Cardiac Anatomy session. SA = Strongly Agree, A = Agree, N = Neither Agree nor Disagree, D = Disagree, SD = Strongly Disagree, $\bar{x}$ = Mean, M = Median, Mo = Mode. Positive denotes mean score is above the $\bar{x}_w$ for the response, Low denotes the mean score is below the $\bar{x}_w$ for the response.

DISCUSSION

When comparing our results to existing literature, we observe both advantages and challenges in using food-based activities in education. In a similar study, the Snack Cake "Dissection", where students dissected a cake to learn neuroanatomical terms, the activity showed that 64% of participants felt increased excitement for the class. The authors also determined that the class required minimal time and resource demands (Watson, 2015). This mirrors the playful and informal approaches that effectively engage students in difficult subjects, such as neuroscience (Masters and Christensen, 2000).

Edible resources, which are gaining popularity in fields like Earth Science, offer nontraditional learners the opportunity to succeed. It also links the arts, literature and sciences together, facilitating interdisciplinary learning. Although some see these activities as juvenile, especially in higher education (Francek and Winstanley, 2004), they can be adapted for older students. For example, activities like the edible cell (Butts, 1972) where the concept of the cell is taught with the aid of fruit embedded in gelatin for secondary school children, could be modified for introductory University courses by asking students to add more complex components e.g., Golgi body, allowing students to apply more advanced concepts or critique and improve on the original models.

Despite the benefits, edible learning models often simplify processes or accelerate timelines of processes, which can result in superficial understanding unless students are guided to critically reflect on these limitations (Francek and Winstanley, 2004). This is a critique in broader edible science projects, where engagement sometimes comes at the cost of scientific accuracy. However, research on experiential learning (Kolb, 2014) underscores that activities providing concrete experiences —such as edible models—encourage observation, reflection, and the formation of abstract concepts.

In a case study by Tanabashi (2021), a science talk on organelles demonstrated the effectiveness of using familiar objects, like sweets and bakery items, to engage children. Initially, traditional slides failed to captivate the audience, but when edible models were introduced, engagement and interest significantly improved. This highlights the value of familiar objects in boosting motivation and positive emotions, especially among younger learners, aligning with broader findings on the benefits of object-based, sensory-rich learning environments. Tanabashi's study underscores how everyday items—like Smarties in our activity—can make abstract concepts tangible, enhancing the learning experience.

Supporting this notion, bioscience projects involving edible elements—where students represent processes such as meiosis with cupcakes, brain structures with cakes, or DNA with sweets—further demonstrate how these activities can boost creativity and motivation (Çömek et al., 2016). Students enjoy the process of creating and tasting models, which increases their engagement compared to more traditional approaches. However, the key challenge is to strike a balance between enjoyment and substantive learning outcomes.

Several limitations of this study should be acknowledged. The experiences shared may not accurately represent the entire Foundation Year Bioscience student population. Participants' opinions, as captured in this study, reflect a specific point in time and may evolve over time. Additionally, the absence of a control group limits our ability to determine whether this approach surpasses traditional teaching methods like in-class lectures. Regarding the measurement of central tendency, the decision to use a weighted average was intentional to enhance the distinction between questionnaire domains (Tastle et al., 2005; Alonazi et al., 2019). While this approach has its merits, it is important to note the ongoing debate about the most appropriate measure of central tendency (Wilcox and Keselman, 2003; Viswanathan et al., 2004). Finally, the use of Smarties as a teaching tool presents practical and ethical considerations, including cost, hygiene, potential allergies, food waste and dietary restrictions. Despite these constraints, the interactive and engaging nature of the activity suggests potential benefits that merit further exploration.

Future studies could examine the long-term effects of edible activities on the retention of neurological concepts, using control groups to provide clearer insights into their effectiveness compared to traditional lectures. To enhance the impact of edible models, incorporating structured reflections or follow-up assessments could reinforce learning objectives and ensure students internalise key concepts. For instance, students could critique the limitations of the Smarties models or propose modifications to deepen their understanding. Additionally, integrating more investigative approaches could enrich the learning experience. For example, students could research the effects of a specific drug, such as nicotine, on synaptic transmission. Each team could design edible models using materials like Smarties for neurotransmitters and gummy worms for axons to depict both normal and drug-altered synapses, then present their findings to their peers. Critiquing and refining these models would further enhance their grasp of physiological concepts.

In conclusion, the respondents found this method of delivery to be a fun activity that improved their understanding of action potentials. They felt the format was appropriate to check their understanding of the topic and to identify their weaknesses. They also felt it fostered good teamwork in which they learned from their team. Further research is required to elucidate whether edible neuroscience is a teaching methodology that will ultimately impact on student attainment

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