From Asymptomatics to Zombies: Visualization-Based Education of Disease Modeling for Children

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ABSTRACT

Throughout the COVID-19 pandemic, visualizations became commonplace in public communications to help people make sense of the world and the reasons behind government-imposed restrictions. Though the adult population were the main target of these messages, children were affected by restrictions through not being able to see friends and virtual schooling. However, through these daily models and visualizations, the pandemic response provided a way for children to understand what data scientists really do and provided new routes for engagement with STEM subjects. In this paper, we describe the development of an interactive and accessible visualization tool to be used in workshops for children to explain computational modeling of diseases, in particular COVID-19. We detail our design decisions based on approaches evidenced to be effective and engaging such as unplugged activities and interactivity. We share reflections and learnings from delivering these workshops to 140 children and assess their effectiveness.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in visualization**.

KEYWORDS

Disease spread, Visualization, Children, Teaching

ACM Reference Format:
Graham McNeill, Max Sondag, Stewart Powell, Phoebe Asplin, Cagatay Turkay, Faron Moller, and Daniel Archambault. 2023. From Asymptomatics to Zombies: Visualization-Based Education of Disease Modeling for Children. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23), April 23–28, 2023, Hamburg, Germany.* ACM, New York, NY, USA, 17 pages. https://doi.org/10.1145/3544548.3581573

1 INTRODUCTION

In March of 2020, when the World Health Organization (WHO) declared COVID-19 to be a global pandemic, many nations of the world instituted lockdowns at great societal cost to "flatten the curve" and limit the spread of the virus. During this difficult time, members of the public tried to make sense of the pandemic and the repercussions it would have over the next two years. To this end, visualizations became commonplace [63] to help the public understand the evolving situation [76]. On a daily basis, citizens were presented with visualizations in order to make sense of data and model results and to come to terms with the "new normal".

Children, in particular, were affected by the pandemic with lockdowns bringing virtual learning and social distancing, meaning that they could not spend time with their friends. It was, and is, important that they understand what is happening around them. As with the general public, making sense of models and data forms a key part of building this understanding. Teaching how diseases are modeled and what effect interventions have on these models directly supports this need. Additionally, it provides an opportunity for young people to explore STEM subjects and computational thinking in general from a practical perspective. By providing this education in a fun and engaging way, we can inspire students to connect with these topics in their studies, and foster understanding of pandemics and the need for public-health interventions.

To this end, we joined forces with an educational partner in the UK called Technocamps to design visualization tools and an associated workshop on the computational modeling of diseases. Technocamps specializes in providing such workshops to primary and secondary schools throughout a predominantly rural region of Wales spread over 20,000 km^2. As noted in a report by NESTA on digital outreach opportunities for young people, "regions other than London and the North West are proportionally very undersupplied [in digital outreach engagements] for the number of young people living there" [53]. The aim of Technocamps is to provide

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CHI '23, April 23–28, 2023, Hamburg, Germany

ACM ISBN 978-1-4503-9421-5/23/04.
https://doi.org/10.1145/3544548.3581573

such opportunities to under-served regions, in order to enthuse and excite young people about computing and digital technology and their ubiquitous applicability in other STEM subjects. A typical Technocamps workshop takes place in a classroom and lasts half a day. Each year Technocamps delivers on the order of 400 such workshops in 200 schools for the benefit of some 10,000 pupils and their teachers, and has been organizing workshops for 20 years.

In this paper, we describe the workshop and the visualizations that we developed which continues to be delivered to about a hundred students aged 8-16 in the UK each month. Specifically, the contributions we make are as follows:

- Simple yet rich disease simulations with associated interactive visualization tools. These are designed for educational use to teach disease modeling and the effect of public health interventions, and to develop students' understanding of computational modeling and computational thinking more generally.
- A demonstration of how visualization can build upon unplugged activities within education workshops to enhance engagement and learning.
- Reflections and learnings from an iterative design process that incorporated perspectives and requirements from an interdisciplinary mix of visualization researchers, epidemiologists and education experts.
- Observations and key learnings building on data and evidence from an educational workshop delivered to 140 young people over 10 sessions.

After surveying related work in Section 2, we describe our workshop in Section 3, and explore in detail the visualization tool we developed for the workshop in Section 4. We evaluate the effectiveness of the workshop in Section 5, discuss the evaluation in Section 6, consider future plans in Section 7 and provide concluding observations in Section 8.

2 RELATED WORK

2.1 Public Health Visualizations

Visualization techniques and systems have been created to support public health initiatives and disease control. Many such systems use information from health records [26, 27, 47, 56] or more broadly visualize data in epidemiology [52]. With infection control experts, visualization approaches have been created to help understand the progression of disease outbreaks in hospitals [4, 50]. At a more general level, approaches have visualized spatiotemporal factors in disease spread [8] and to help support decision-making [42, 75]. Specific to COVID-19, the visualization community made great efforts to help support the data science response [12, 19]. A number of visualizations have been developed focusing on situational awareness [18, 41, 43], contact tracing [3], and the effectiveness of simulated government policies using contact tracing networks [65].

The above visualization methods have mainly been used to make sense of models and data by experts. In contrast, there has been relatively little work on creating visualizations to make models accessible to the general public, with simulation based approaches being the best known. The Guardian [20] used a static particle model with animated colors to explain the role of variables such as R_0 (the basic reproduction number) and isolation. The Washington Post's 'Simulitis' [66] used randomly bouncing particles to demonstrate the spread of a fictional disease and the impact of different types of intervention. Salathé and Case [59] use storytelling methods alongside animated line charts of simulation results to explain the effect of various interventions, and Simler [64] used a simple grid-based simulation to illustrate the role of various parameters. The work described in this paper lies in the gap between expert models and minimalistic illustrative models: we develop a simplified but non-trivial particle-based infection model, and use interactive visualization to teach children about disease modeling and computational thinking in general.

2.2 Public-Facing Visualizations

A number of papers have investigated how accessible visualizations can be used to inform the general public. These public-facing visualizations have been studied, for instance, in the context of museums [32, 33] and book collections [68] to understand how the public uses visualizations. Narrative visualizations, or how people tell stories with data, have been explored in the context of media and other sources of information [2, 35, 36, 61]. Strategies for communicating data specifically about people have been explored in the anthropographics literature [7, 48, 49]. The 7-dimensional design space introduced by Morais et al. [49] can (to some extent) describe the particle simulations we use in this work: they have high *granularity*, *specificity*, *coverage* and *authenticity*, and low *realism*, *physicality* and *situatedness*.

For COVID-19 in particular, a number of studies examined how visualizations informed, or misinformed, the public in-the-wild. Zhang *et al.* [76] analyzed hundreds of visualizations used to communicate the state of the pandemic from official sources to the intended audiences. Lee *et al.* [40] examined visualizations circulating on social media that promote controversial views. In our work, we design public-facing visualizations aimed at children in an educational setting to explain concepts in disease modeling for infectious diseases, and evaluate this in the wild.

2.3 Engaging with Children

2.3.1 Data Physicalization and Unplugged Activities. Employing unplugged activities as a pedagogic device for introducing and teaching computer science, with no sight or mention of computers, was first promoted two decades ago [6]. Various studies have since then supported the use of unplugged activities in effectively teaching topics in computing to young people, be it computational thinking [9] or programming [5, 31].

In our developed workshop, we use a number of unplugged activities where students manipulate real world objects to make sense of disease models. These activities share similarities with data physicalization [37, 69] where physical objects are created to share and communicate data. By physicalizing the data, we transform the abstract into something tangible that can be interacted with, which can have a myriad of benefits [38]. In our case, we use unplugged activities to make data concrete and explain concepts behind disease modeling to children.

2.3.2 *Visualization in Education.*

The importance of data visualizations in educational settings, in particular in order to help children learn STEM concepts, has been explored by visualization researchers. Firat and Laramee [23] provide a useful survey of research into pedagogical visualization, and point out that the use of visualizations for education is rapidly growing. Gates [25] provides an extensive review of using visualization in the teaching of STEM subjects in early secondary education. Visualization literacy itself has also recently received significant attention [22], building off earlier work in making visualizations "for the masses" [30, 70]. Studies have found that there is generally a low level of visualization literacy [11], but educational efforts have been made to address this [1, 10, 14]. For example, *C'est la Vis* [1] presents an interactive app for teaching bar charts to elementary school children.

The common theme in the above studies is the means by which visualizations bring the subjects they explore to life, making them engaging and – if done well – fun for young people. This element is key to the Technocamps approach to delivery, and a concentration on visual presentations is fundamental to many of its workshops [67]. This is especially so in the case of the current workshop [46] which we developed for teaching disease modeling concepts specifically through and using data visualizations.

2.3.3 *Digital Education in Schools.*

In the last decade, the UK has increased the emphasis on computing and digital technology in its school curriculum. Whilst this is recognized as essential in providing the necessary pipeline into the increasing, and increasingly, digital workforce, there are serious educational and socio-economic barriers to this. There is clear recognition of a lack of training in the subject amongst the nation's teachers [45, 62, 74], leading to the establishment of *Computing At School (CAS)* initiative in England [16]. The NESTA report [53] highlights the lack of support offered to rural regions of the country. The necessity of an initiative such as Technocamps to provide sustained engagements for these geographically, and socio-economically, hard to reach areas is essential.

In terms of engaging effectively with children, the key element is to develop workshops that are relatable and enjoyable. Making our disease modeling workshop relatable is trivial, as it explores the unnatural world of social distancing in which the children found themselves. This would be enough to fully engage adult learners; but including fun elements is crucial to maintain the interest of children. This is what motivated us to frame the disease modeling workshop in terms of a zombie apocalypse. Films such as *The Night of the Living Dead* and *White Zombie* have captured the imagination of children and adults alike. Thus, our workshop activities and visualizations were designed with this theme in mind.

Simulations stimulate exploratory learning [17] by letting the students adjust the various parameters, and are well suited to facilitate learning of complex skills [13]. Various papers [21, 54, 55] have demonstrated the usefulness of simulations in teaching science-concepts, and Serious Games in general [51]. As summarized in the meta-analysis by Cherniokva et al. [13], introducing a simulation early in the learning process supports the restructuring of knowledge into higher order concepts. In our workshop setting, the visualization of the simulation allows the children to use the visualization as a medium of discussion for collaborative learning of disease spreading concepts.

2.3.4 *Teaching Infectious Disease Spread to School Children.*

Kafai et al. [39] provide a useful scoping review of such activities for teaching spread of infectious diseases over the past two decades. They found that while there is research on how young students can develop a basic biological understanding of what happens, there is less concern about more complex aspects of spreading diseases such as asymptomatic individuals, which are a critical factor in the spread of diseases like HIV/AIDS, Ebola, and COVID-19.

There are a few approaches that take more complex disease mechanics into account, for example those of Colella [15] and Rosenbaum et. al [58]. Both of these use the method of Participatory Simulations, where students use a wearable computer to simulate a disease in progress. This resembles our unplugged activities (although with a device) using the children as the agents of the disease with a similar playful approach to engage them. While these approaches have an expansive activity with digitized devices to include complex behavior, we keep our physical simulation simple and unplugged and use it as a building block towards understanding the visualization of a more complex simulation for quick exploration. This simulation allows us to increase the students' understanding of the scientific and socio-scientific aspects of infectious disease epidemiology, which was identified as one of the main limitations in current work by the review by Kafai et al [39].

3 TECHNOCAMPS WORKSHOP DESIGN

We present here our design of visualization tools and an associated workshop. Our approach is based on our partnership between 4 visualization experts, 2 external epidemiology researchers (25 and 9 years of experience in epidemiology research), two members of staff from Technocamps (20 years and 10.5 years of experience organizing these workshops), and motivated by the successes of digital, visual and collaborative methods in education. Since Technocamps regularly deliver educational workshops, we build on their expertise and adopted the operational structure of a typical Technocamps workshop as our framework. The typical Technocamps workshop lasts half a day, roughly 2.5 hours, is delivered within a classroom environment of 25-30 school children aged 8-16 from predominantly rural areas, and involves an interleaved mixture of three approaches to give an experience-based learning session.

1. At the start of a workshop, and at regular intervals throughout, children are asked to pay attention to a short **presentation**, delivered in a conversational way in which they are encouraged to contribute. By pausing to reflect on their experiences, the children are converting these experiences into learning.
2. The second part of the workshops consists of **unplugged activities**, which form a core of Technocamps workshops in general. Here, children have almost free reign to play games and solve puzzles which are designed to reflect the topics that are being learned in a fun and engaging way.
3. Finally, in a more structured yet still fluid way, elements of **digital technology** are introduced which the children use to solve problems closely aligned with the unplugged activities. These may, for example, be devices or software

> packages, and typically require the children to program in some sense to solve problems. In this paper, we explore the use of visualizations of disease models in this role.

Such experience-based learning is recognized as being a very effective pedagogic principle, and is being incorporated into the national curricula in the UK: the national curriculum in Scotland from 2018 [60] that is based on *Experiences and Outcomes (Es and Os)*; and the national curriculum in Wales from 2022 [71] that is based on *Areas of Learning and Experience (AoLEs)*.

The design of this workshop is based on a number of ***learning objectives*** that were agreed on collectively by our team of visualization and epidemiology researchers and Technocamps . Our goal is that, with our approach, students should be able to: **(i)** understand complex concepts and processes in epidemiology and public health, **(ii)** explore and experiment with different disease spread scenarios and parameters, **(iii)** apply their knowledge of epidemiology to real-world situations, **iv)** develop computational thinking skills and an appreciation of computational modeling, and, **(v)** develop their social and teamwork skills. In the remainder of this section, we give an outline of the three parts of the newly developed disease modeling workshop that aims to address the above learning objectives.

3.1 Presentation

The workshop begins with a short presentation that introduces the participants to the topic of the workshop: *Modeling Zombies!* At this point, the narrative of the workshop is set:

> *'Zombie outbreaks are scary. Especially if you are really popular and know lots of people who could potentially be a zombie. Today, we are going to model a zombie outbreak using something called a contagion process.'*

Throughout the workshop, activities are paused at regular intervals to turn attention back to the presentation, in order to connect the unplugged and visualization activities to the science being explored. The presentation briefly explains the basics of concepts such as probability, networks/graphs, contacts, disease modeling and public health interventions through quizzes and discussions.

3.2 Unplugged Activities

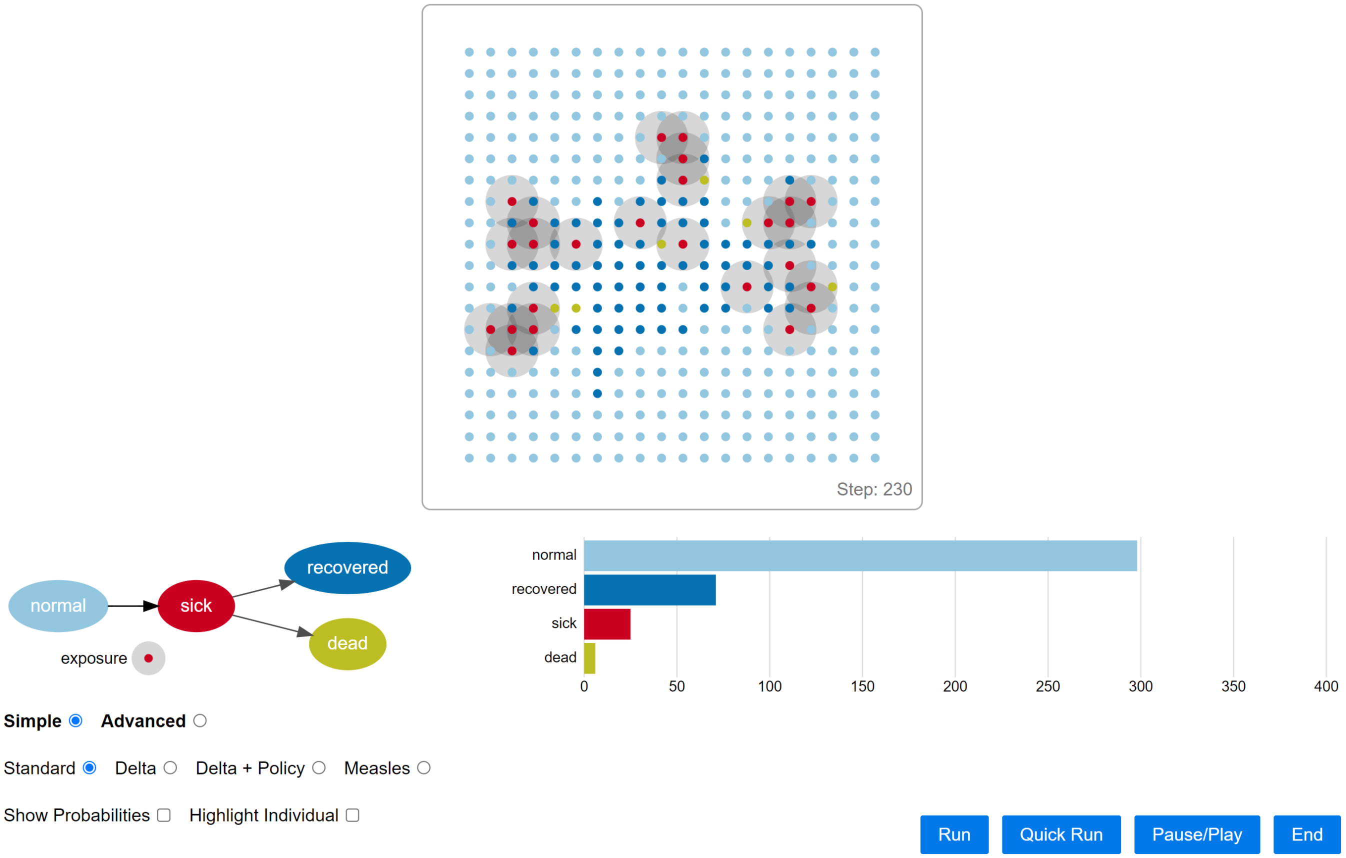
After the introduction, the workshop continues with an unplugged activity in which an infectious disease propagates through the classroom. We first introduce the concept of state in order to track the zombie infestation. We start with two basic states: a green state to represent an uninfected member of the class; and a purple state to represent an infected member of the class; i.e., a zombie. We then introduce the notion of a simple contagion process whereby, at any given point in time, an infected member of the class can infect a nearby classmate by flipping a coin. The class tracks the spread of the zombie apocalypse using string to represent infections between two participants. In some scenarios, the whole class becomes infected almost immediately; and in others, the zombies take much longer to infect everyone. The string is useful for investigating the history of an infection, from one infected person back to "patient zero". Using the participants and the string, we are physicalizing the simulation, blending data with the children to create an embedded data representation [73] that is easily understandable for the children and lets them actively engage in the creation of the "visualization".

This first activity inevitably raises several important questions about the spread of diseases which are then discussed using the structured presentation component of the workshop. Can a person recover from the disease? Can a person die from the disease? Is there any known vaccination against the disease? With these questions in mind, new states are introduced: a blue state to represent a member of the class who has recovered from or is immune to the disease; and a yellow state to represent a zombie that has died. The participants then re-run the process and notice the differences that these new states create, as well as the added complexity of tracking them. After exploring this on paper and trialing it several times, attention is brought to the idea of how this could be a way of understanding how real-life infectious diseases spread in the real world. It is quickly agreed that you would need to be able to track the state of each participant – which even with a small number is quite complex – and that you would need a lot more participants. The conversation is turned towards using a computer to do this, which is when the visualization tool is introduced.

3.3 Visualization Tool

The visualization tool we developed provides a simple interface for participants to explore the spread of an infectious disease. The basic visualization (Figure 1) is a model of the unplugged activity so it is easy for students to transition from the physical approach to the digital approach. Since the visualization uses a much larger population (400) than the unplugged activity (25-30), students can immediately appreciate an important benefit of using a computational model. In the visualization, each person is represented by a static particle (circle) and the infection state of each particle is represented by color. If a particle is infected, a light gray circle indicates which other particles it could potentially infect. Initially, participants are challenged to run the simulation using the default settings and investigate the different outcomes produced by running the model several times. This is an important step for participants to reinforce the randomness of these simulations, noting that the simulations will run and evolve differently each time.

The role of different model parameters is explained to the class bit-by-bit. They can set parameters themselves or opt for pre-set parameters for existing diseases — various COVID-19 variants or measles — and consider the relative dangers of these diseases. After exploring the basic model, students are introduced to a more advanced model (Figure 2) which includes particles moving between 'home' and 'work/school' in a daily routine, as well as additional infection states (such a asymptomatic) and parameters (such as probability of vaccination). This shows the students how models can be made more realistic and capture elements of their own lives and the issues they hear about relating to the COVID-19 pandemic. At this stage, students have gone from a simple physical model, to a sophisticated computational model (with respect to their existing knowledge) and are once again given time to explore and discuss how different parameters interact with each other, how they impact the simulation results and the extent to which the model reflects real life.



Simple ● Advanced ○

Standard ● Delta ○ Delta + Policy ○ Measles ○

Show Probabilities ☐ Highlight Individual ☐

Figure 1: The simple Particle People model. The top view shows a disease spreading. Particles (colored circles) represent people and do not move. Color represents infection state. Gray circles represent the range of disease exposure by an infected individual. Bottom left shows the infection state transition diagram. Bottom right shows an animated bar chart with the distribution of infection states.

3.4 Visualization Requirements

Based on our learning objectives (Section 3) and further discussions with the epidemiologists and Technocamps, we established a number of requirements for the visualization and associated simulation. These also generally reflect good practice derived from years of delivering Technocamps workshops.

(1) 8-year old children should be able to understand the visualization with minimal explanation: This is our lowest-age target audience.
(2) The visualization has to reflect (simplified) epidemiological models: As the goal of the visualization is to educate, we need to ensure that the information that is shown is correct, even if simplified to match the target audience.
(3) The visualization should be usable by individuals on their own or in small groups: Allowing the children to interact and experiment with it directly themselves reinforces their understanding.
(4) The visualization should be easily accessible via tablets and PCs: The attention span of a child can quickly be exceeded with tedious technical set-ups prior to getting them involved. This also impacts the amount of time available for the children to explore and learn in a time-limited workshop.
(5) There should be enough depth in the visualization: In a half-day workshop, there could easily be one hour of time for the children to experiment with the visualization in a guided way. There should thus be enough content for the students to interact with and learn from the experience.
(6) The simulation should run quickly enough to allow for experimentation: This allows the children to rapidly experiment with it and get an intuition into the effects of changing the different parameters. A slowly-reacting simulation can easily result in losing the attention of the children.
(7) The visualization should feel fun to the children: Engaging and fun content captures and maintains the attention of the children and facilitates their engagement with the subject.

Requirements 1, 2, 5 and 6 are specific to our workshop setting, but are not too far away from a more general classroom setting. Requirements 3, 4 and 7 can be seen as general requirements for interactive and individual-based educational visualizations.

Simple ○ **Advanced** ●

Standard ○ Delta ○ Delta + Policy ● Measles ○

Show Probabilities ☐ Highlight Individual ☐

Probability that ...

Get vaccine 0.1 *per day*

Infected when exposed to asymptomatic person 0.4 *per person per day*

Infected when exposed to symptomatic person 0.8 *per person per day*

Asymptomatic when infected 0.3

Stay asymptomatic 0.3 *per day*

Stay symptomatic 0.6 *per day*

Figure 2: The advanced Particle People model. The top view shows a disease spreading. Particles move around commuting from home (top) to work/school (bottom) at regular intervals. When the Delta+Policy option is enabled, some individuals (black circles) isolate at home. The bottom view shows some of the interactive options; other options (not shown) include the total number of people, how many houses there are, and how fast the particles move.

4 VISUALIZATION DESIGN PROCESS

To help the workshop audience explore the ideas introduced in the unplugged activities (Section 3.2), we developed the Particle People visualization[1] which visualizes the spread of a simulated infectious disease using particles (colored circles). Our aim was to produce an engaging resource to help students better understand how phenomena such as exponential growth and community spread arise from individual interactions, and how varying disease parameters and public health interventions influence the spread.

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[1] https://contact-viz.cim.warwick.ac.uk/particle-people/

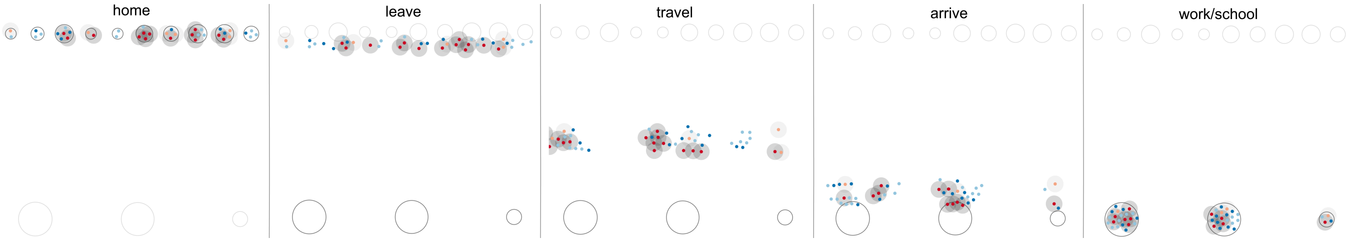

Figure 3: The phases of the advanced Particle People model during the 'morning commute'. People start at home then travel to work/school. After arriving, they pause at work/school for a while then travel back home (not shown).

4.1 The Design Challenge

A challenge when visualizing complex systems is communicating both the high-level behavior of the system, and the low-level parts and interactions which drive this behavior. In our case, the high-level behavior is how a disease spreads through a community in space and time; the low-level features which drive the spread include properties of the disease itself, properties of the individuals the disease infects, how these individuals interact, and specific actions/interventions that impact the spread of the disease. Over the course of the pandemic, a number of visualizations have been designed to support the understanding of COVID-19 models [12, 19]. When designing an interactive visualization for such a complex system, there is a natural tension between including enough elements to enable rich behavior and interesting exploration, and making it understandable, comprehensible and accessible. This tension is particularly relevant here given the wide age range (8-16) and ability range of our audience. Specifically, we required a resource that weaker students could confidently interact with from the outset, and yet with sufficiently rich behavior that stronger students could enjoy exploring it for an extended period.

4.2 Initial Design

From a visualization perspective, an intuitive approach to mitigating the design tension discussed above is to use a simple, clutter-free visual encoding. This is exemplified by successful 'particle-based' approaches to communicating epidemiological concepts which represent each person as a particle (colored circle) [20, 29, 66]. Of particular relevance to our design challenge, is the 'Simulitis' Washington Post article by Harry Stevens [66] which shows how a fictional infectious disease spreads through a community: People (i.e. particles) move on straight trajectories, and the disease is spread when an infected person collides with a susceptible person. This simple approach effectively demonstrates how exponential spread arises. Furthermore, it can simulate quarantine by adding 'walls', and simulate lockdown/social distancing by restricting the number of particles that move.

Given the visual simplicity and previous success of particle-based approaches, we used them as a starting point for our design. However, existing approaches [20, 29, 66] use simple, abstract models as part of a linear 'visual storytelling' narrative — reflecting their purpose as news articles designed to clearly communicate a few key concepts. Relative to these approaches, we aimed to develop a more realistic, interactive model of how infectious diseases spread to encourage exploration and discussion. Two design decisions were particularly important in this respect. Firstly, we replaced the random trajectory movement model of Simulitis with a simple pattern of urban activity whereby particles commute between home and school/work (Figures 2, 3). This allows users to better appreciate the dynamics of how a disease spreads through a community. As an example, the user might see two infected family members travel to different workplaces; one of these people may spark a major outbreak at their work, while the other may not infect anybody at work. From a participation perspective, we anticipated that the commuting model would resonate with users since it will better reflect their own experience — whether they are focused on a single individual in the model, or observing the rhythmic daily pattern of the community.

The second major design decision was to introduce a more detailed disease spread model. Rather than an individual being infected with certainty by an instantaneous interaction (a collision), we introduce a proximity-based model whereby the probability of a person becoming infected at a specific time is based on how many infectious people are nearby (Figure 4). This is a more accurate reflection of how infectious diseases spread. Visually we use a gray exposure circle around infected people to allow for tracking the magnitude of a person's current exposure. During the initial design stage, we investigated combining the commuting movement model with collision-based infections which involved people randomly moving around inside their current 'building'. However, the movement and interactions of people were much more difficult to track compared to the final design where people are static once they reach their destination.

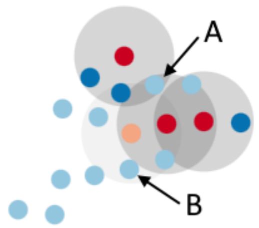

Figure 4: A and B are susceptible (light blue) and exposed to the disease (gray circles) through proximity with infected individuals (red/pink). A is exposed to two symptomatics (red) so has a higher probability of becoming infected than B who is exposed to one asymptomatic (pink).

Given that our visualization should be 'fun' (Requirement 7 in Section 3.4), there was a risk that a minimalist particle-based approach would promote simplicity at the expense of engagement. A potential improvement would have been to anthropomorphize the visualization further by replacing particles with "wee people" [28]. However, it is unclear if such approaches are effective [7, 48], and given the reasonably fast animation in the visualization and the overlap-based exposure model, we felt any potential advantage of wee people was outweighed by the impact on clarity.

We also considered appearance options and alternative layout for the 'town' which could potentially increase realism and engagement. However, as we kept the appearance of the particles simple, using a more realistic appearance for the town would result in style clashes, and hence we kept the appearance of the town simple as well. Changing the layout of the town to be more realistic resulted in long commutes which decrease the speed of the model, which in turn decreases the time for experimentation with the parameters. Hence, we opted to also keep the layout simple.

4.3 Iterative Design

To help us find a good balance between scientific accuracy and accessibility for children in particular, we followed an iterative design methodology based on an ongoing collaboration with epidemiologists at the University of Glasgow and the Technocamps team, who were also responsible for delivering the workshops. Here we discuss how we respond to the different priorities from the collaborators.

Responding to epidemiologists: Feedback from the two external epidemiologist researchers involved was vital for ensuring that our model was sufficiently realistic, and also for guidance on which aspects of disease spread were most critical to communicate. While their time was limited (influencing our methodology [12, 65]) due to the ongoing pandemic, we discussed several designs with them during critical stages of the project (initial sketches, final sketch, first implementation, and near-final implementation) in order to ensure the epidemiological concepts were not misrepresented as well as highlighting the concepts they felt were most important. For example, they felt very strongly that asymptomatic cases should be included since this is a feature that distinguishes COVID-19 from many other diseases, and a poorly understood concept by non-experts. One interesting observation is that they understood well the difficulty of teaching the various concepts involved, and were understanding and even supportive of thinking about simplifying epidemiological concepts. For instance, they suggested representing multiple named diseases using different preset transition probabilities, even though these settings can only capture the rough characteristics of the diseases.

Responding to education specialists: Technocamps's experience in developing for a school setting allowed them to have a clear vision of what would and would not work with respect to both model complexity and the user-interface. Furthermore, close collaboration with Technocamps ensured that the digital part of the workshop integrated seamlessly with the unplugged activities described in Section 3.2. For example, Technocamps suggested the simple computational model of the unplugged activity (Figure 1) to bridge the gap between the unplugged activity and the advanced Particle People model (Figure 2). We had anticipated that Technocamps would act as a counterbalance against the temptation of developing too complex a model. In reality, they were broadly in support of adding model features (and interaction to control them) so that ambitious students had more options for exploring ideas, and were confident that the additional complexity could be managed by good workshop design and delivery. Furthermore, they suggested a liberal approach to parameter ranges, believing that students would enjoy searching for parameter combinations that would lead to extreme, unusual or unrealistic outcomes — and further their understanding by doing so.

4.4 Final Design and User Interface

The final design of the visualization tool includes two models: a simple grid-based model of static particles (Figure 1) that directly mirrors the 'string and coins' unplugged activity described in Section 3.2 and an advanced model (Figure 2) where particles commute between 'home' and 'school/work'. This enables a natural progression in the workshop from the unplugged activities, to the use of computational modeling, to considering a more sophisticated model which captures (in a simple way) patterns of urban activity.

Both models are inspired by an agent-based compartmental model [44] which has been used to model the spread of COVID-19 for contract tracing [65]. In these agent-based compartmental models, each person is represented by a node (in our case: a particle) with a disease state (healthy, symptomatic, etc.) and transitions between disease states are probabilistic. Crucially, the probability of transitioning from an uninfected state to an infected state is only nonzero when the person is exposed to the virus (in our case: a person is within the gray 'exposure circle' of an infected person, Figure 4). The state transition diagram for the current model ("basic" or "advanced") is shown below the particle visualization. Users have the option of switching between different preset transition probabilities labelled as 'Standard' (COVID-19), 'Delta', 'Delta + Policy' and 'Measles' which approximate the relative differences between these diseases. At any point, users can change the transition probabilities and rerun the simulation. Some probabilities are initially set to zero, so changing these effectively adds new features:

- Isolation can be enabled by changing the probability that a person isolates when symptomatic. An isolating person is not infectious, and we show this using a thin black circle around the person instead of a gray exposure circle. In the advanced model, there is also the probability that asymptomatics isolate (which can be seen as the level of community testing), and all isolating people stay at home while infected.
- Vaccination can be enabled by changing the probability that a person is vaccinated. A vaccinated person immediately transitions to an immune state.

Children can also change various model parameters. For example, the minimum and maximum capacities of houses and offices/schools, the number of people, and the radius of exposure circles.

We follow standard practice with particle-based approaches [29, 66] (and agent-based modeling mode generally [72]) of displaying an aggregate plot next to the visualization which allows the user to easily track the global behavior of the system. In our case, we use an animated bar chart to display the infection state distribution at the current time. When the simulation ends (i.e. nobody is infected), the chart is replaced with an area chart showing the complete history of the infection state distribution over time.

The visualization is implemented in JavaScript and does not require any setup other than a tablet/computer with internet access.

4.5 Ethical Considerations

Before proceeding with any of the workshops, we obtained approval from the university's ethics review board for the workshop and collecting of the data for research purposes. Technocamps has approval from the Welsh government to organize educational workshops for schools.

COVID-19 and infectious diseases are clearly sensitive topics. However, we consider it of great importance that children understand how diseases spread and why governments impose restrictions that so heavily impact their daily lives. This requires teaching them how disease models work and that they are not perfect; they are stochastic in nature and changes in parameters can lead to different outcomes. While this means that children can explore extreme outcomes (e.g. spreading the disease to everyone) when actively interacting with the model which is a potential risk, we believe this is outweighed by the benefits of increased engagement and the children learning about such an important concept with an extremely high impact on their daily lives.

5 EVALUATION OF "MODELING ZOMBIES"

Following its initial development, the workshop was first trialed to the general public as part of a two-day Science Festival. Due to pandemic restrictions, the groups taking part were small: a total of 35 participants took part in the four workshops provided, with 14 participants of young people within our target audience, the remaining 21 being parents and pre-school siblings. Though only our target audience were asked to provide questionnaire feedback, it was interesting to observe the parents taking part in the activities, and it was clear from their comments and interactions with the visualization tool that the workshop was thought-provoking and intriguing.

Feedback from the trial sessions allowed us to make minor tweaks to our workshop before deploying it in six school-based workshops involving 126 students. The evaluation provided in this section reflects these 10 sessions involving 140 participants (14 from the science festival sessions plus 126 from the schools). The participants are aged between 8-16, with the bulk of them between 9-12 and come from predominantly rural areas. The workshop has, in the meantime, entered the mainstream catalog of Technocamps' offerings; it is a popular workshop, and has been delivered on more than 50 occasions in different schools (averaging more than once per week) to over 1200 young people.

In order to evaluate our approach in the wild [57], we designed a mixed methods approach which involved gathering data from the students, their teachers and the Technocamps facilitators who ran the workshops. We made use of printed surveys (selected questions in Table 1) that were distributed in-class before and after the workshops to the participating students. The teachers (who are in the room during the workshops as observers) also filled in a printed survey before and after the workshop with a different set of questions. Finally, after the Technocamps facilitators ran several workshops, we conducted semi-structured interviews with two of the facilitators to gather data on their experiences and observations delivering the workshop. We had considered a more traditional education evaluation approach with a pre- and post-test to assess student learning. However, an important goal of Technocamps workshops is to make STEM and computational thinking fun and engaging, and it was deemed that formal tests would negatively impact the workshop in this respect. Moreover, student engagement can be better measured using qualitative self-assessment than traditional tests. Therefore, our approach relies heavily on surveys for evaluation similar to *C'est la Vis* [1] that engages children with visualization in STEM in the wild.

Survey design & Methodology. As discussed above, we conducted surveys before and after the workshop. Building on Technocamps's experience that students are unlikely to respond to long surveys, the constraint was to keep the surveys to a maximum of two sides of an A4 paper. The first side was used to ask routine data gathering questions that Technocamps normally asks, and could not be changed as this would no longer match the data in all their other workshops. Hence the context-specific survey questions were limited to a single side of an A4 paper (both for the teacher and student surveys).

We use the pre-workshop survey to establish a self-assessed baseline of the students' knowledge of disease spread and computational modeling and their interest in STEM subjects. The post-workshop survey is used to assess the educational value of the workshop and the visualization in particular, and to determine whether it increased interest in STEM subjects.

We gathered 140 student responses and 4 teacher responses during the workshops, which were digitized by Technocamps admin. Questions either used Likert scales or were open text questions. Questions using Likert scale responses were analyzed quantitatively. Open text questions were analyzed using open coding [34] with two coders, who first independently coded the results by labelling responses with an initial set of concepts. Each coder then consolidated the concepts into a small set of overarching themes, before meeting to compare and refine the themes into a set of agreed themes. They then used the final themes to re-code the responses for the analysis. In the analysis, we ignore blank responses, but we include these in the figures for completeness.

5.1 Student Surveys

We start by analyzing the 140 responses from the student surveys using the questions shown in Table 1. We first analyze how much and what students learned during the workshop, and then explore the impact of the visualisation. Finally, we consider whether students' interest in STEM improved due to the workshop.

Self-Evaluated Learning. We compare how much students knew about how different diseases spread (Pre-Q9), with how much they learned about how diseases spread (Post-Q7). Figure 5-a shows the result of these two questions in a matrix plot. The vast majority of students (81%, 99 out of 122 students) indicated high factors of learning (4 or 5) in the post-workshop questionnaire. Even for students that indicated they already knew "a lot", the majority (66% 6 out of 9 of students) still indicated the maximal level of learning (5, "a lot"). This provides evidence that the workshop was on the whole effective in terms of creating a feeling of learning.

ID	Question	Answer options
Pre-Q7	How interested are you in the following subjects? One answer each for: Science, Technology, Engineering, Maths	Very interested, Interested, Not Interested
Pre-Q9	How much do you know about how different diseases spread?	5-point scale from "a lot"(5) to "nothing"(1)
Pre-Q11	How much do you know about why lockdowns, self-isolation and vaccinations happen during a pandemic?	5-point scale from "a lot"(5) to "nothing"(1)
Pre-Q11a	What do you think the effects of lockdowns, self-isolation and vaccination are?	Open question
Pre-Q12	What do you know about modeling diseases using computers?	Open question
Post-Q2	How would you rate today?	Great, Good, OK, Poor, Bad
Post-Q5	Would you like to learn more about: One answer each for: Science, Technology, Engineering, Maths, Computing	Yes, Maybe, No
Post-Q7	How much did you learn today about how different diseases spread?	5-point scale from "a lot"(5) to "nothing"(1)
Post-Q8	Did you enjoy using the simulation to explore disease models?	5-point scale from "a lot"(5) to "nothing"(1)
Post-Q9	Which part of the workshop did you learn the most from?	Presentation, Physical activities, Simulation
Post-Q10	How much did you learn today about why lockdowns, self-isolation and vaccinations happen during a pandemic?	5-point scale from "a lot"(5) to "nothing"(1)
Post-Q11	What did you learn from this workshop about modeling diseases using computers?	Open question

Table 1: Student-survey questions that are analyzed in Section 5.1. ID contains an identifier to the question, with "Pre" and "Post" respectively indicating if this question was asked before or after the workshop.

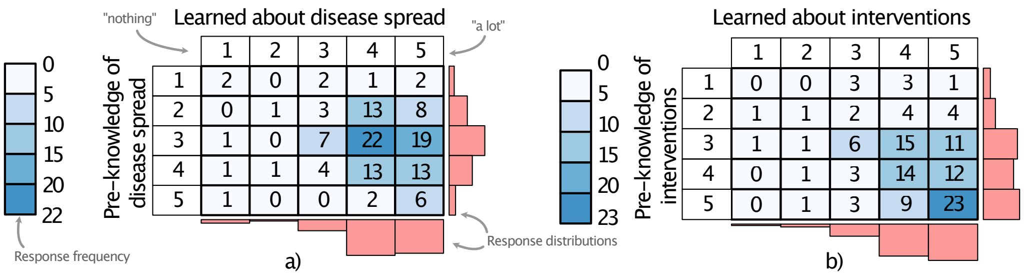

Figure 5: Matrices comparing: (a) how much children know about disease spread (Pre-Q9) before the workshop against how much they learned (Post-Q7), (b) how much children know about why interventions happen (Pre-Q11) before the workshop against how much they learned (Post-Q10). Overall, children report learning "a lot" from the workshop, even when they expressed already having substantive knowledge before the workshop.

Further evidence on learning is obtained by comparing how much students knew (Pre-Q11) and learned (Post Q-10) about why lockdowns, self-isolation and vaccinations happen during a pandemic. The results of these questions are visualized in Figure 5-b using a similar figure as before. While the self-assessed pre-knowledge of interventions is high with a mean value of 3.7 and skewed towards the higher numbers, the self-assessed learning after the workshop observed to be higher (4+) for the vast majority of students (81%, 96 out of 119). Again, even for students that indicated that they already knew "a lot", the majority (62%, 23 out of 37 students) still indicated the maximal level of learning (5 "a lot").

Effects of lockdowns and isolating. We originally intended to continue our analysis by open coding questions Pre-Q11a and Post-Q11 in order to determine the shift in the views of the students. However, after performing the coding and attempting to analyze the data, we concluded that the questions are too different to allow us to draw sound comparisons. Hence, we do not compare the results

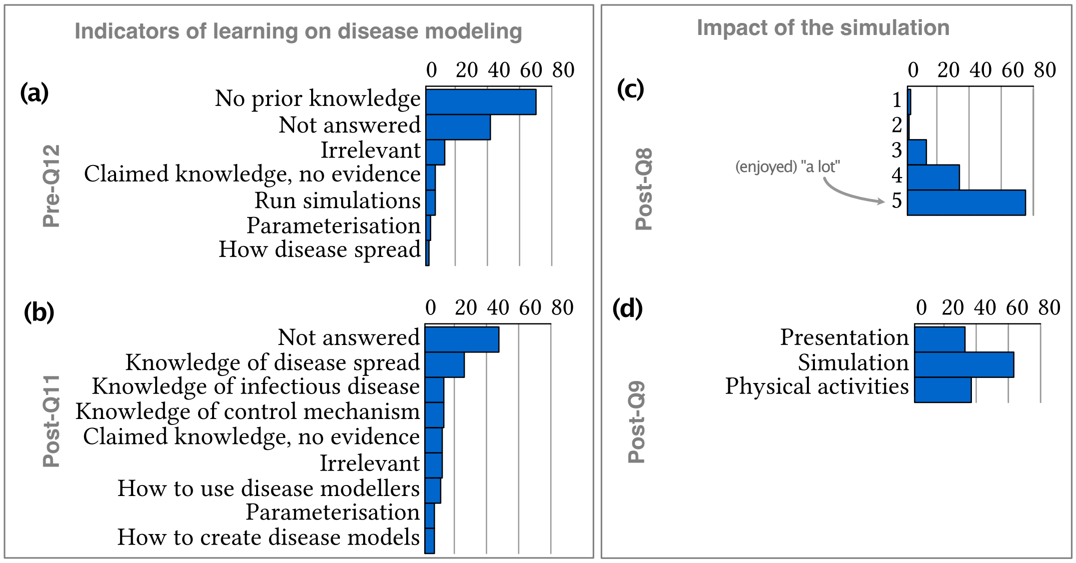

Figure 6: Analysis of the survey data. (a) Coded student responses on what they know about diseases modeling pre-workshop (Pre-Q12) (b) Coded student responses on what they know about diseases modeling post-workshop (Post-Q11) (c) Student responses on how much they enjoyed using the simulation to explore disease models (Post-Q8) (d) Student responses on which part of the workshop they learned the most from (Post-Q9) which highlights simulation as the most enjoyable overall.

of these in this paper. However, there is one salient detail that is worth remarking upon in Pre-Q11a: "What do you think the effects of lockdowns, self-isolation and vaccination are?". We expected the students to give rough description how it is helping stem the disease and preventing infections around themselves. What we did not directly expect, as our team mostly has seen COVID-19 from a researcher perspective, is the emotional content in these responses. Among other answers, students mentioned "it is to keep you safe" and "sadness", looking at COVID-19 from a more emotional perspective instead of an abstract problem-driven angle. We find it important to highlight this, as this is something that can easily be overlooked.

Indicators of learning on disease modeling: We continue the analysis of learning by analyzing the open questions. We first explore what the students knew (Pre-Q12) and learned (Post-Q11) about modeling diseases using a computer. Here, the coding process (discussed earlier), focused on "identifying common themes that relate to learning about disease modeling using computers" resulting in a number of themes. Figures 6-a and 6-b respectively show the frequency of the agreed-upon themes for pre- and post-workshop responses. At the start of the workshop, the majority of the responding students (71%, 70 out of 99 students) had no prior knowledge of how to model diseases with computing. After the workshop the students responded with a wide variation of facets of knowledge (76%, 71 out of 93 students) with only relatively few students giving irrelevant answers (12%, 11 out of 93 students) or not giving any evidence (12%, 11 out of 93 students). For instance, the students talked about "mechanisms of disease spread", e.g., "*that people get sick by going out and getting closer makes you ill*", or about "parameters", e.g, "*Different factors/variables affect the spread a lot i.e. isolation, social distancing.*". While the children do not write extensive amounts of text (due to space, time and attention limitations), the wide variety of responses concerning disease modeling provide evidence that the workshop as a whole was effective in communicating different factors in disease modeling.

Impact of the simulation. We first analyze whether the children enjoyed using the simulation to explore disease models (Post-Q8, Figure 6-c). The vast majority of the students (88%, 108 out of 123 students) indeed enjoyed using the visualization (4+), with only a few (3 out of 123 students) expressing that they didn't enjoy it (2-).

As students are more engaged and learn more when enjoying the material, we expect to also see this when we analyze which part of the workshop (Post-Q9) the children felt they learned the most from: the presentation, the simulation, or the physical activities (Figure 6-d). We observe that most students (48% (63 out of 131)) indicated that this was the simulation, with the presentation (24% (32 out of 131)) and physical activities (27% (36 out of 131)) being nearly equal. An ordering effect may be present due to the setup of the workshop, but nevertheless this is a strong indicator that the children found the visualization of the simulation educational and useful.

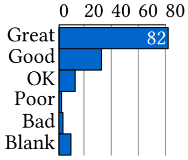

Figure 7: Post-workshop student responses on how they rated the workshop. The workshop was well received by the children.

Enthusiasm for STEM. Figure 7 shows how the students rated the workshop (Post-Q2) on a scale from bad to great. The majority (63%, 82 out of 131 students), of the children

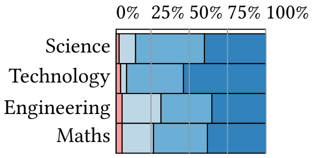

Figure 8: Pre-workshop student responses on how much they want to learn about STEM subjects (not interested, interested, very interested) (Pre-Q7). Darker blues indicate more positive responses. Red bars are blank responses.

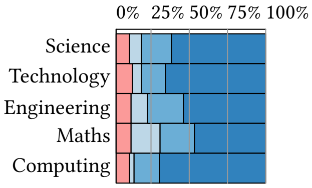

Figure 9: Post-workshop student responses on whether they want to learn about STEM subjects (no, maybe, yes) (Post-Q5). Darker blues indicate more positive responses. Red bars are blank responses. Compared to Figure 8, overall interest for all STEM subjects is higher after the workshop.

rated the workshop the best possible "great", while only a few (4%, 5 out of 131 students) rate the workshop below the middle point of the scale "OK". This shows that the workshop as a whole was enjoyed by the students and indicates to the children that STEM subjects can be fun and interesting.

We additionally provide evidence for this by comparing the pre-workshop interest (Pre-Q7) of children in STEM subjects (Figure 8) with the post-workshop interest (Post-Q5) in STEM subjects (Figure 9) that were asked in the standard Technocamps survey. Before the workshop, the vast majority (84%, 456 out of 541 over the 4 questions) of children already indicated interest in STEM subjects, but many were only "interested" (2) and not "very interested" (3). It is clear that in terms of interesting children for STEM subjects, the workshop in general is a success: Before the workshop on average 44% (239 out of 541 over the 4 questions) of the children were "very interested" in STEM subjects while after the workshop 64% (324 out of 504 over the 4 questions (ignoring computing)) of the children want to learn more about STEM subjects after the workshop. The changing in phrasing from "interested in subjects" to "like to learn more about" may have influenced the results slightly, but we expect that this effect is minimal. Due to Technocamps's comparability constraints to their other workshops, this phrasing could not be changed.

5.2 Teacher Surveys

The teachers also filled in both a pre- and post-day survey aimed to evaluate the workshop and interactive visualization from an educational and teacher point of view. Out of the 4 teachers that filled in the survey, two of them taught computer science subjects before. They all teach children between ages 7 to 11 (KS2), but had a mixed background in how often they used visualizations in their teaching (1,3,4,5). One of the teachers had taught about disease spread before, and mentioned that the most difficult part to teach is understanding the concept of how it spreads.

The teachers overall rated the workshop well (4,4,5,4), and were positive on the visualization being helpful for the students to get a better understanding of disease spread (5,5,X,4) and computer models (4,4,X,3). Teacher 3 did not fill in the second part of the survey and thus has blank (X) marks. Teacher 4 indicated ICT issues in the workshop, but overall was still positive towards the visualization. They indicated that the interactivity had additional benefits over static visualizations ("Yes", "yes absolutely", X, ICT issues) and would incorporate (interactive) visualizations into their teaching available (5,4,X,5). While a relatively small sample size compared to the 140 children, this sketches an overall positive image of the workshop as a whole and interactive visualizations in particular.

5.3 Facilitator Interviews

5.3.1 Methodology & Protocol. To gain insight into how the facilitators experienced working with the interactive visualization and how the children interacted with it during the workshops, we performed semi-structured interviews with two of the workshop facilitators, denoted as F1 and F2. Both F1 and F2 are Computer Science students working with Technocamps who have delivered around 4-5 different Technocamps workshops, doing each workshop numerous times.

During these semi-structured interviews we asked the facilitators a series of open questions about their experiences during the workshop. We focused on questions to determine what the impact of including the visualization was, and what the children learned from the workshop. One author of this paper was holding the interview, while two other authors took notes to evaluate later.

5.3.2 Analysis & Results. The overall feedback from the facilitators about the use of the visualization in the workshop was very positive. It was helpful for the children to *"F2: see how scenario's in real life can be brought in large scale in real time"*. It was mentioned that the usual Technocamps workshops stop at the level when it becomes too abstract and thus: *"F1: The visualization is a useful extension of the activities"*. In the workshop the context went from physicalization to an abstract model, which in the view of the facilitators helped the children with grounding their knowledge: *"F2: If we went straight into the app[visualization], it might be harder. Easier with the physicalization when they can put themselves in. When we get to the computer, they already know the concepts we are trying to teach them."*. Having both the physicalization and the visualization helped as well to adapt the class on the fly: *"F1: Less energy class, we are doing less physicalizations. Skipping to the viz because it's more personal and play with it around on it's own."*.

The visualization in the view of the facilitators was often used by the children as a kind of "game". More specifically, in this game they created, they tried to change the colour of the dots on the screen to a particular outcome: *"F2: Race to see who can spread the disease the fastest... peering over each others screen and egging each other on.*, *"F1: Kids are making a game of it to get everyone sick..."*, and the children enjoyed the general setup of it *"F1: The kids love the game [viz+gamelike]..."*. This matches with the responses from the children where they indicated they enjoyed the simulation in Section 5.1. While they used it as a game, this provides evidence that they did gain further understanding of the mechanics behind it *"F1: (a) kid managed to get everyone dead [sic: infected] but one and was excited that they managed. Managed to do a proper explanation how they managed that. Seemed to understand it quite well."*, *"F1: Lots of kids trying to kill everyone, trying to experiment how to get the fastest spread. They did get to understand what infected people."*. In the more advanced model, *"F1: They really properly explored advanced model ... It's very relatable to COVID, they are interested in exploring. It related to what they are experiencing. In 1 to 1 they always say something relatable."* which indicates that the visualization grabbed their attention in multiple ways and they could understand it both on an abstract level and a personal level.

The visual design has both an animated and a static part. The animated part drew their attention more *"F2: They are more gripped by the particles than the statistics. F1: Confirm"*, *"F1: Animated was much more engaging opposed to the static stop."*. In particular, *"F2: Kids cared more about the grid with particles than information of the graphs. More about seeing the virus moving around rather than just the statistics."* and *"F2: They can see people moving and interacting, it sort of abstracts it a bit less. See it more as people, and less abstract."* which couples back towards the physicalization activities that allow the children to better connect with the abstract model through a visualization.

They also had a few remarks for improvement, in particular *"F2: Some of the words were difficult, and they didn't quite know what they were."* and *"F1: Asymptomatic is new for the younger kids at least."*, which led to *"F2: Kids could get into a point where they couldn't get back."* and had to refresh the page to have a baseline model to explore. In this particular case, the choice of including asymptomatic was deliberate after discussion with epidemiology experts on the main difference between various diseases, but nevertheless deliberate care should be taken on word-choice, especially when working with young children. Finally it was *"F1: 50-50 if they catch on to the exposure radius, even after exploration"*.

6 DISCUSSION

In Section 5 we evaluated the workshop and visualizations using three different sources: (1) Survey responses from 140 students, (2) survey responses from 4 teachers, and (3) semi-structured interviews with 2 workshop facilitators. Each of these different sources provided evidence that the workshop was educational for the children to learn about modeling disease spread and be inspired about STEM subjects. The students' enjoyment (Figure 6-c), support for the visualization (Figure 6-d), and high overall rating of the workshop (Figure 7) provide compelling evidence that the visualization design was fit for its purpose. The detailed interviews with facilitators provide valuable insight into why the design was successful and how it might be improved. For example, some of the technical terms, such as 'asymptomatic' proved to be a challenge for some, and a few concepts such as the 'exposure radius' were not immediately clear. These are concrete suggestions that can be addressed with further explanations in the presentations or a different choice of wording. Iteratively evaluating and improving the visualization tool as more workshops are delivered is a potential methodological consideration for educational projects such as ours.

In the following sections, we discuss key learnings that could support the future design and development of workshops involving interactive data visualizations for classroom-based learning.

Interdisciplinary Collaboration for Classroom-Based HCI

By designing the visualization together with epidemiologists and education researchers, we were able to develop an accessible and engaging visualization for educational purposes while also ensuring that the underlying model sufficiently reflected the mechanisms by which infectious diseases spread. For example, we added asymptomatic cases to the advanced model on the advice of epidemiologists (Section 4.3) and since the workshops have been running, a review by Kafai et al. [39] has highlighted how rarely this important aspect of infectious disease modeling is included in educational interventions aimed at children. Regarding our collaboration with Technocamps, the physical-to-digital workshop structure is a *concreteness fading* [24] approach whereby new concepts are introduced with concrete examples and then faded to the more abstract. Alper et al. [1] found that concreteness fading is commonly used when teaching data visualization to young children and observed promising results when children used their interactive *C'est la Vis* app which incorporates concreteness fading. We suggest the feedback collected from our workshops provides support for concreteness fading in a related context: the use of interactive visualization in more complex topics with an older age group.

More generally, the need for an interdisciplinary team in this project was clear: none of the groups involved had the requisite expertise to design, develop and deliver the envisioned educational resource. However, effective interdisciplinary collaboration is rarely as simple as assembling multiple groups that collectively have the required skills. In this project we made a range of interesting observations that were central to the success of the project, and that we believe can benefit the planning of similar projects in future:

- Both epidemiologists and educators agreed that communicating the fundamental processes (of disease spread) were more important than realistic parameter ranges and results. Indeed, the epidemiologists' suggestion that we include named diseases was to show their relative infection rates and other distinguishing characteristics such as measles having no asymptomatic cases. Having to only capture these high-level dynamics allowed us to focus on aspects of the design which helped understanding the process and on engagement — such as the town's layout and the time taken for a single simulation.
- The epidemiologists and HCI research team were planning to limit interaction to only the most important parameters to avoid confusing a young audience. In contrast, Technocamps persuaded us to make many parameters interactive to ensure that students (and the stronger students in particular) have the opportunity to explore the model, if they wanted to. A key observation here is that educational resources for the classroom are not standalone; instead they are typically used under the guidance of a professional teacher who knows their students — or in this case, a facilitator that is experienced in delivering such workshops to

mixed ability groups. Both the workshop structure and the individual(s) running it play a role in how the visualization is used at each stage of the workshop and providing appropriate guidance to students of different abilities. In contrast, it is the developers' responsibility to ensure that the resource is sufficiently rich and engaging for the strongest and most curious of students.

- Our collaboration with Technocamps highlighted a number of challenges that are particularly pertinent to HCI-education collaborations. Firstly, the visualization element (or use of HCI more generally) is typically embedded in a larger session and careful planning is required regarding where and how the visualization is used. In this project, we used an unplugged activity to introduce concepts prior to using the visualization, but also (on the request of Technocamps during the iterative design process), the simplest simulation (Figure 1) was a model of the unplugged activity. The second crucial challenge is that of assessment. In this project, we aimed to give school-age children an interesting introduction to some crucial concepts in disease spread, but also to further their computational thinking skills and introduce them to the power of computational modeling in general (Section 3). Given these learning objectives and the less formal nature of Technocamps workshops, we decided self-assessment was appropriate. While many of the survey responses were useful, many were very short, unclear or nonsensical. The facilitator interviews went someway to providing some of the deeper insight we had hoped to gather from the students' responses, but we suggest that future workshops of this type include similar interviews with a subset of the students, or a semi-structured class discussion at the end of the workshop to get valuable feedback directly from the participants.
- The epidemiologists' involvement in this project grew out of an existing collaboration initiated by the COVID-19 pandemic [12, 19]. This meant the visualization researchers had developed useful domain knowledge in infectious diseases, and likewise for the epidemiologists regarding visualization. It also meant the teams were used to communicating and had established an effective language and level at which to do so. While the work reported in this paper was successful from both a research and impact perspective, it is unlikely to have been conceived had it not been for the existing vis-epidemiology collaboration — and if it had been, it would have been much more laborious and had to go through a similar period of development of collaborative relations. This demonstrates an important point for HCI researchers collaborating with other disciplines: collaborations have a significant set-up cost so it is important to maximize the potential of collaborations by looking for both follow-on research and and crucially (given the unique position of HCI) opportunities for impact, engagement and education.

Particles are Fun

Generating interest and engagement is crucial when dealing with a young audience and it was particularly interesting that students' enthusiasm was often due to their interpretation of Particle People as game-like. This has interesting implications for designing interactive visualization in school settings. Firstly, the simple appearance of Particle People did not seem to deter engagement, suggesting that particle-based approaches are appropriate for such resources, and more generally, that adding appearance purely to drive engagement is not necessary. This is important since it allows resource designers and developers to focus on clarity and accuracy. Secondly, students perceived our standard simulation (and non-game-like) approach of 'set parameters then run' to be exciting. This suggests that (as with appearance) adding extra interaction purely to drive engagement is not necessary. It should be noted here that the Particle People simulation typically only takes 2-15s for the simple model and 5-90s for the advanced model. Hence, student's see each 'game' as spanning multiple simulations where they iteratively explore or try to improve towards their desired outcome. Finally, it is clear that the particle visualization captured the students' imagination with little attention being paid to the aggregate plots. While this provides further support that particle-based approaches (and likely unit visualizations more generally) encourage engagement, it also indicates they should be used wisely since they are likely to be the focus of attention when shown alongside more standard visualizations — perhaps particularly with a younger audience.

Relatability and Discovery

We believe that the students related to the Particle People simulation (Section 3.3) because it captures their daily life in a simple way: they travel between home (where they mix with family) and school (where they mix with classmates), and have experienced how an infectious disease can impact this routine. Intuitively, this relatability means the model gains a student's attention and as they watch the animated visualization they start to appreciate the higher-level dynamics of how the disease spreads (such as how it jumps across groups with overlapping members) and how it can be stopped. However, watching one simulation has its limitations: it does little to explain the role of different variables that drive the process or how they interact. Furthermore, simply watching the simulation is a passive experience which can easily lose the attention of a young audience. Adding interactive parameters solves both these problems by allowing students to actively engage and discover the role of at least some of the different variables. This was particularly appropriate here – and for Technocamps' style of workshops in general – where the learning objectives (Section 3) are more loosely defined than in a traditional lesson. In this workshop, it was perfectly acceptable if, for example, one group of students learned more about the role of the infection rate while another group focused on vaccination. This reflects the findings of Chevalier et al. [14] where open-ended exercises were given for creating and using interactive visualizations using a tablet. There they found that it can engage students deeply and foster curiosity to help promote active learning. In contrast, when the objective is for students to learn specific information, we suggest that narrative visualizations [66] or hybrid narrative-interactive approaches [20] are more suitable.

We believe that this simulation-based approach that combines relatability and exploration can serve as a useful template for future workshops, and have written prototypes simulations for transportation and urban planning with this in mind.

7 FURTHER WORK

This paper suggests various intriguing avenues for future work. The engagement of the children with the visualization despite the simplistic layout of the 'town' and the simple appearance of the particles was an interesting finding. However, we believe that deeper exploration into possible layouts and styles is warranted. For example, more realistic and heterogeneous town layouts will have more nuanced infection dynamics which may elicit more intricate exploration, consideration and learning from the students. We could consider layouts with multiple alternating rows of home and work, a radial layout with houses on the outside work on the inside, or a town-like layout comprised of streets arranged around larger work buildings. While these would result in more complex patterns of infection, the trade-off is that the commuting pattern are unlikely to be as clear as in Particle People. From an appearance perspective, visualising simulations using 2D sprites might increase engagement and make it more game-like, at the cost of it being harder to visually discern patterns of spread and interesting behavior. Building better dialogues with the gamification literature and exploring new ways of introducing game-like narratives with interactive visualizations, and studying their impact on learning is likely to be a fruitful research area.

8 CONCLUSION

In this paper, we developed interactive visualizations of disease models which we embedded in a workshop for children with the aim of fostering an understanding of disease spread and the effects of public health interventions on pandemics. Our visualizations build upon unplugged activities to give children a more detailed understanding of disease models. We report on the design process where we incorporate the perspectives of epidemiologists and education experts, and on our learnings of aligning visualizations and unplugged activities in educational settings. We evaluated the workshop and visualizations using survey responses from 140 children and 4 teachers, as well as 2 semi-structured interviews with workshop facilitators. We observe that our approach is successful in engaging children about computational modeling of disease spread, engaging them in the material, and fostering interest in STEM subjects.

At the time of writing, the workshop continues to be delivered to around 100 young people every month. Through Technocamps, we are continuing to generate interest in computational thinking and computational modeling of diseases through visualization to many children in under-served regions of the UK.

ACKNOWLEDGMENTS

This work was funded by the UKRI EPSRC Grants EP/V033670/1 and EP/V054236/1. The authors would like to thank Sibylle Mohr and Louise Matthews for their collaboration on the design. We would also like to thank Abena Amo, Kane Pirankar and the team at Technocamps for their help in reaching a diverse audience.

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