UNIVERSITY OF COPENHAGEN
DEPARTMENT OF SCIENCE EDUCATION

The project Science Moves was created to explore didactic and expressive questions in using kinaesthetic exercises to learn about science. It was an activity, offered in the context of Science in the City, a science communication "fair", which was the public side of the conference European Science Open Forum, held at Carlsberg, Copenhagen, June 2014. We developed material in collaboration with researchers in the fields of motor control engineering, past disaster science, and synthetic biology and held several workshops where participants enacted kinaesthetic models to represent scientific ideas. We learned about the conditions for collaboration with expert scientists, interactions with the general public and identified several kinaesthetic mechanisms.

Science Moves

– Report on a series of workshops where the public engage with scientific ideas through kinaesthetic models

Di Ponti & Jesper Bruun

IND's skriftserie nr. 40, 2015

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University of Copenhagen

Introduction

The project Science Moves was created to explore didactic and expressive questions in using kinaesthetic exercises to learn about science. It was an activity, offered in the context of Science in the City, a science communication "festival", parallel to the conference European Science Open Forum. While there is some research in this area, it is still a very new field, where sound cases of practice are lacking. It was the intention, with Science Moves to develop material where participants enacted kinaesthetic models to represent scientific ideas. While those models were constructed, we learned also about the conditions for collaboration with expert scientists and interactions with the general public. During this project, we have developed written material that can be used for teaching and disseminating complex scientific ideas, while at the same time producing empirical data that can be used both as a documentation of the process and for science education research.

The ideator and producer for this project was Di Ponti, though early on, the project became a collaboration between Di Ponti and Jesper Bruun, postdoc at the Institute for Science Education, University of Copenhagen, and together we developed the material and facilitated the workshops. I am thankful to Jesper for all the companionship and support, from the planning, to the enactment, and to the comments and suggestions to this report.

I. Development

Perhaps because it was a pilot project, or perhaps because of the nature of reality, this project had many unknowns to start with, and at least as many during its process. To establish collaborations was challenging. We sent letters to many of the ESOF participants, and few replied. From the positive answers, we initiated collaboration with different groups of scientists. We found that initiating and working in depth with scientists on their current research is likely to result in usable kinaesthetic models. However, not all our collaborations were fruitful. In one case, collaboration fell through, though we had already created the exercises for their research in collaboration with them and their students. Thus, even far into the process of developing kinaesthetic models in collaboration with scientists, the process may fail. In the case of these particular scientists, they expressed that they were doubtful that their research and their results would be conveyed with sufficient attention to their complexity.

The establishment of the relation with Science in the City, and the Tent of the University of Copenhagen was strenuous to say the least, with immense numbers of bureaucratic emails often changing the agreements and conditions, where we saw a greater enthusiasm for appearances than for content, and much uncertainty about the nature of the event. When we finally were there, we realized that it was more a fair than a festival, it was completely top-down in its organization and only caring about catching people's attentions for a short span of time. Their only important measure was the number of visitors, and yet, the space always felt empty. In other words, we perceived it as a hostile environment for active enquiry, a space where passivity was accepted. While we did establish collaboration with the school programme of the Science in the City, and received two 7 grade classes, they failed to follow up on the promised collaboration with the high school "performer" ambassadors. Mostly for that reason, we were not able to keep through the goal of having a "performative" part of each kinaesthetic exercise after the workshop part, nor was it possible to create the "scripts" in collaboration with these students, to focus more on process and on getting observations for a research project.

The funding situation hindered the ability to engage in artistic collaboration. Science in

the City provided information about one fund for science communication. However, the information turned out to be outdated. This was really too bad, because funding would have allowed for interesting artistic collaborations. For example, there were preliminary meetings with Bent Nørgaard, the former director of the Center for Art and Science at the University of Southern Denmark who was ready to collaborate if there were funds, and there were proposals to a dance group, E Pur Si Muove, which didn't materialize.

Collaborations

We collaborated with four research projects to transform parts of their research into kinaesthetic models. We created a playground that served as a bridge between the research and the public, between the ideas and their expression. The collaborations were very different, not only in the content, but also in the levels and numbers of people with whom we collaborated. This contributed to a great diversity in the experiences, to a richness in the project and a greater space for learning and concrete pedagogical experiments.

For the "Science Moves: Synthetic Biology", we worked directly with Professor Birger L. Møller, the leader of Center for Synthetic Biology (CSB) at the University of Copenhagen and with research coordinator at CSB, Nanna Heinz. We met with them for a first brainstorm, which resulted in a first draft of the model. We then planned and carried out a workshop which included both faculty members and PhD students from CSB. After the workshop, we made a second draft of the model and had CSB members comment, edit and suggest changes. We tested this changed version in a workshop for a group of approximately 10 volunteers [the Volunteer Workshop (VW)], and made further corrections (in collaboration with CSB) based on that test. For the "Science Moves: Past Disasters", we worked with Associate Professor Felix Riede, leader of the Center for Past Disasters at Aarhus University. Our first meeting with Felix was via Skype, and we proceeded with further drafts and brainstorming at a face to face meeting in Copenhagen, before testing a draft model at the VW. For "Science Moves: Electric Motors", we worked with PhD Fellow Esteban Fuentes from the Technical University of Munich. We met several times to brainstorm and try out different models with small groups of people. After testing the models at the VW, we made small changes as with the other models. As

for the chemistry one, we collaborated with Bachelor of Chemistry Julie Faber, who at the time was doing her bachelor project on kinaesthetic learning activities with Jesper as her supervisor. We supported her in creating a script and facilitated her work with the chemistry model in the VW workshop. As can be gathered, our collaboration spanned many layers of academic life, international as well as national partners, and different faculties and disciplines.

Research

While we were working on development, we were also interested in collecting data and making collaborations at the research level. We worked with Dr. Sarah Davies, postdoc at the Department of Media, Cognition and Communication who was studying several science communication projects at Science in the City. We also worked with Associate Professor Marianne Achiam, Department of Science Education, University of Copenhagen who researched the Science Moves project from an affordances and informal learning perspective. Due to the richness of the design process and the enactments, Science Moves is likely to result in several papers that bring together different voices, including those of the "doers" and those of the "observers". Part of this arrangement was to write down our reflections on the process. Another part of the arrangement was the collection of data from different parts of the process in the form of audio and video recordings. All of these different formats serve as empirical data for planned papers.

Lessons Learned I - Phases of development

As we worked on the development and the collaboration with researchers, we identified several phases that we went through, namely:
1. Making contact (in person, phone and/or email): explaining the concept and the objectives (developers)
2. Reading material (scientific papers, slides, popular science articles, PR-material): getting a sense of what their research was about, what issues were important, and acquiring some basic vocabulary of the research area (developers)

3. Creating budding ideas: kinaesthetically based explorations about what might be conveyed and what mechanisms to use in kinaesthetic learning activities within the research area (developers)
4. Brainstorm session (developers and researchers) that includes
   - understanding the material
   - collaboration about possible learning outcomes
   - proposing ideas in a playful and open manner, thinking aloud, doodling, discussing
   - choosing avenues to pursue while dropping others
   - getting clarity on the core of the research and what researchers want participants to learn and explore with kinaesthetic learning activities

5. Writing a work-in-progress document with exercises (developers)
6. Feedback on the document (researchers)
7. Test session (with a group): trying out the exercises, developing them together
8. Do any of the above a number of times, depending on the time and energy remaining until the workshops.

II. Workshopped Enactments

We had eight time slots during Science in the City. Two on Saturday, two on Sunday, and one time slot each of the following days until Thursday. All workshops except one (due to lack of participants Wednesday evening) were carried out successfully. Each workshop had very different groups of participants: classes of school children, adults with children, and only adults. As our room proved difficult to find, we gathered people at the tent of the University of Copenhagen after the chemistry show. The table below summarizes the enactments.

Workshop No	Name	No Participants	Participants	Comments
I	Synthetic Biology	9-10	Three families	
II	Electrical Motors	22-24	Mixed adults and children	
III	Past Disasters	12-13	Mixed adults and children	
IV	Chemical Bonds	7-8	Adults	With Julie Faber

V	Synthetic Biology	20	Mixed ethnicity	
VI	Electrical Motors	20	Homogeneous ethnicity	
VII	Past Disasters	8-9	Adults	

Documentation

Three different groups filmed the workshops, each group with a different purpose. Workshops I and II were filmed by a group of students who were working for Sarah Davies, who was studying different science communication projects. For this project, the Science Moves project was part of a comparative study. Workshops I-VII were filmed by Marianne Achiam for research on affordances of kinaesthetic learning activities in informal settings; to try to understand what kind of learning was taking place in between the fun and playfulness. We also carried voice recorders in every session. Cecilia Wörlén filmed workshops III-VII for the purpose of creating an artistic film that captures the tone of the events.

In the Appendices are the following documents, crafted by Di Ponti and Jesper Bruun:

Appendix A: Pitch,

Appendix B: Science in the City website,

Appendix C: Work-in-Progress "Science Moves: Synthetic Biology",

Appendix D: Work-in-Progress "Science Moves: Electric Motors",

Appendix E: Work-in-Progress "Science Moves: Past Disasters".

Lessons Learned II - Phases of enactment

Upon reflection about the enactments, we have identified phases of the enactment that seem to be key phases:

1. Gathering people: having a group of interested participants is key
2. Intro: introducing the project and ourselves
3. Warm-up: group exercises where participants move around in the space, bringing attention to their own and others' bodies, inducing a playful mood while introducing some generic kinaesthetic exercises
4. Setting-up: explaining the set and/or the first exercise
5. "Playing": trying out the exercise
6. Elaboration: space for group work, reflection on the learnings and questions
7. Possibly more 4, 5 or 6 in any combination
8. Sum-up: closing the session, feedback

Roles

Creating such a project made us understand that there are many roles needed, all of which we fulfilled, to a greater or less extend: the role of "producer", *i.e.* contacting the diverse collaborators and setting the conditions for realization; the role of creating props; the role of organizing research; the role of "animators"/facilitators - creating an activity for all of the present; the role of taking data; the role of being a contact person with ESOF – all of these were roles that we took. It became evident that we drew much from our previous experience in facilitating which was a necessary asset for the execution of the workshops. And yet still, it was surprising how much we needed to be "on", how exhausting it was, how much improvising was needed, and how much energy we used in adapting to a varied audience.

Work with adults and children

We had different challenges in working with adults, children and mixed groups. The main quest in the work with adults is to support them into a space of playfulness, where questions are allowed as well as welcomed, a space of trying out, of curiosity. In our experience, the adults (self-selecting themselves to be there) were quite open. Those

who had their children, interacted immediately to convey and bridge understanding to their children. As for the children, there were several times when we had to down-scale the explanations to be able to include them. While we didn't expect the kids to fully understand the science in these 'playgrounds', we hope to have conveyed that science can be a playground, a place of inquiry and curiosity, where it is ok to ask, try out, and experiment.

Lessons Learned III - Discussion

The didactic and the expressive

These are the two main practices around which we developed this project. The didactic reminded us that learning outcomes needed to include verbs like "doing" and "being", clear guidelines for the workshops to help structure the experience, moments for answering questions and discussing with other participants as well as time to make doodles of understanding. The expressive reminded us that it had to be engaging, interesting to try, that we needed to set up a physical space and use easy-to-understand props to create a space of playfulness and exploration.

By using both the expressive and the didactic practices, we consider that kinaesthetic representations can help participants formulate interesting questions which can help both their own understanding and might even, contribute to further steps in research processes. This is our motivation to collaborate with science in the making and not only design kinaesthetic models based on textbooks. We believe that these two directions of learning are what (science) communication should be, a two-way process.

Modes

Kinaesthetic models can be used in a variety of ways. Here, we describe two, but there are probably many other ways of using kinaesthetic learning activities for science teaching and communication:

1. **Co-creating the model**

In this one, facilitators help participants create or elaborate on a kinaesthetic model or game-like situation. It supports people in coming up with their own questions, and supports engagement. Needs more time and entails less control from facilitators.

2. **Gaming the model**

In this one, facilitators control the participants in what is analogous to a computer simulation. It affords researchers to ask more specific questions, to control the rules within the enactment, and the ways in which people interact. While it does not foster high-level learning outcomes, it is less time-consuming and can still be very engaging for participants. Thus, it will often be a better fit with our fast moving society.

In both cases, plans for facilitating and documenting learning processes are essential – especially since we want to improve learning. However, since learning outcomes are qualitatively different in the two levels, different kinds of planning are needed as well as different materials to support reflection that leads to learning. For example, a sheet with open questions may be helpful when co-creating models, while guides for enacting specific parts of the model may be needed when playing the models.

Mechanisms

We have adopted the word "mechanism" as a way to denote "a basic way of doing" that is used in enactments of a particular kinaesthetic model. We will always identify at least one mechanism during the design process of a model. An important part of our learning was to understand what mechanisms were possible and what they offer. Here, we present four mechanisms that we have used for specific models. We believe that they are general and may be used also in other models.

1. **Mechanism "The clockwork"**

This mechanism asks everyone to do a different task, and together they make something function as a whole. They could be parts of a clock, or the internal mechanisms of a cell. Using this mechanism needs time to set it up, so that everyone understands their role. Whenever possible, we suggest that participants exchange roles, to try to be in other positions. The enactments should help to consolidate participation and understanding of the whole. Key points during enactment: Ask questions about the whole clockwork, provide/elicit feedback to/from people enacting different roles. See "Science Moves: Synthetic Biology".

2. **Mechanism "Be the Apple"**

It is sometimes claimed that Newton realized what gravity was when an apple fell on his head. Steve Paxton, contact improvisation pioneer, spoke about "being the apple", for his new dance form focused on experiencing gravity and weight; one's own, and the one of the partner(s). To feel what it is to "be the apple". In this mechanism, the participants are asked to feel in their own bodies what it is to be weight, traction, or being subjected to a force on a field. This mechanism intends to support the creation of a physical "intuition", about where to go or do. The enactment consolidates a sense of what is happening. See "Science Moves: Electrical Motors".

3. **Mechanism "Flock"**

In a flock mechanism, the whole group is activated at once, performing the same activity, but this activity, performed individually by each, has consequences for the whole. In its original sense, the participants act like birds, which have rules of relating to birds/people near them, and when they do so, they act as a flock. It could also be molecules of water recreating flow, or groups creating mathematical shapes. This mechanism engages everyone and it creates a light and lively atmosphere, at times closer to some forms of dancing. The enactment consolidates a sense of being particles in a bigger group. This was used in the warm-up of the workshops.

4.   Mechanism "Represent peoples and choices"

A mechanism where each person has a higher degree of freedom and can make choices and represent more people-related groups – single people, tribes, communities, countries. This mechanism resembles in many ways a role-play game. Also, as it is more "human" it can become more of a game, with issues of "winning" and "losing" being present. Another worry is that it can bring or mix several psychological or political layers. But, on the other hand, it probably is more appropriate for the social sciences and the humanities. This enactment consolidates the participation in a social process. See "Science Moves: Past Disasters".

Playground

Creating a "playground" was essential to induce a playful atmosphere. We chose to use simple and accessible props, low-key, to make it accessible and affordable. This was mainly done by:

- Using **yarn** and tape to set up the floor – in one case as a cell, in another as a map, and in the other as a coordinate system.
- Using (making, collecting) props and **toys**. An example from each of the workshops is the following:

  ▪ **The hula-hoop electric motor:** to explain the workings of an electrical motor, we constructed two sets of two giant hula-hoops which represented wires. These "wires" had a "current" running, which alternated between one and the other wire. To represent the current, we set a "token electron" – a ring that could move through the wire. Establishing people to show the magnetic field line, to push or pull depending on the magnetic field and the current (and their directions and intensities), and someone to be a switch – we could show how electrical energy was transformed into kinetic energy, and how the double hula-hoop started to rotate.

The hula-hoops were used as a learning object – to be "inside" a motor, and could be used for a group to learn and then teach another group.

- **The Velcro DNA:** inside of the cell, at the nucleus, we wanted to show how the DNAs double helix opened and a RNAm copied the information of the DNA. We did this using Velcro with colour pieces attached to it. First, the participants were asked to open the black stripe of Velcro DNA, and then asked to attach a white Velcro RNAm stripe to one of the black ones, and with pieces of colour (for each information-pack) copy on the white stripe the information from the black stripe.

- **The Lego jewellery:** we wanted to represent the pieces of "jewellery" found around Europe about 13000 years ago. An important aspect of these collections is that they were put together with objects that had their origin in different parts of the continent. Lego pieces immediately appeal to the construction and putting together of these objects. People wandered through the landscape, collecting the Lego pieces, putting them together and trading with other "peoples". Their different colours helped to keep track of where these treasures were coming from.

Considerations/Observations

On enactment

- What people are is what they will remember best. When planning, it is important to focus on what the learning outcomes are, and trans-

form those into actions and representations. If one wants to teach a process, then the people should have to act the process.

On scale

-        There is a continuum between representing something smaller than a person, a person or something bigger. This is a good consideration in the beginning of the process and of the brainstorm – what can people represent? Electrons? People? Planets? Populations?

On gaming

-        An element that wasn't much explored in this project was the use of games and game-like activities. These have the great advantage of being engaging, but the serious drawback that "winning" can become more important than learning/playing/interacting. Also, competitive games may not reflect the nature of the social processes. Moreover, it is an extra art to make good game mechanisms, especially if these are to be collaborative instead of competitive.

On active inquiry

-        The workshops were much more revealing than a lecture to know who was learning, questioning, engaging because they made space for an inquiry process that was active, and not so controlled.

Future Perspectives

Although this project explored many questions and possibilities, it even opened more. It would be extremely valuable to develop more material, more content, more mechanisms, more enactments, and also more material to support others to create kinaesthetic exercises and learning games. One possible avenue would be to develop collaborations with Experimentarium or SkoleTjeneste, to work further with children, youngsters and

families. Another avenue is to introduce this methodology as a research tool – for example for people working in a lab to use it for lab meetings or to develop theory or for cross-disciplinary teams to present their research to each other – asking them to enact their own research. That would contribute to the development of common questions when people from different disciplines work together.

We would like to further investigate collaborative games and kinaesthetic ways of playing and learning and to create spaces where research and communication of research happens in a blend of inquiry processes, reflection, playfulness and artistic expression. We would also like to create scripts for improvised performances/flash mobs with knowledge and meaning at their core.

APPENDIX A

SCIENCE MOVES

A series of happenings where the public perform moves to scientific ideas

If you would be up for making a double helix of people, holding hands with the neighbour neuron, or dance how the oceans will rise, you are welcome to our series of happenings where science meets flash mobbing.

Scientific models are often presented using abstract representations: mathematical formulae, graphs and highly specialized diagrams, vocabulary and jargon. But what about using other representations – using the body, creating movements, mingling with crowds – and having fun?

In these happenings, you will be using your kinaesthetic senses to learn and "enact" different abstract objects, in a concrete way. Kinaesthetic models usually involve people acting as the objects of the models. In physics, they may represent particles; in biology, they may represent cells, organs, predators, prey; and in computer science, people may represent bytes of information.

There will be a happening for each of the themes of the conference. We invite you to come and share the challenge of representing specific scientific findings and discussions using our bodies and our togetherness. For each, a score, a guide, will be set up - a set of rules or limiting factors and transitions – that will guide the participants through the performance. Four of the happenings will be preceded by a workshop, which will go into greater depth about the construction of these kinaesthetic models.

These activities support learning by doing and the healthy combination of movement and thought. While playful and memorable, they can create the conditions for questions to arise, both for further understanding of the science and for new insights for the science. Everyone is mobilized, and curiosity is stimulated in each of us.

APPENDIX B

http://scienceinthecity.dk/en/event/12-science-moves

#12 - Science Moves

HANDS ON ⏱ Sat 21.06 - 10.00am-8.00pm ⦿ Wonder District

Workshops at 11-12 am and 14-15 pm.

Join these activities and help create a double helix of people, simulate a brain using handshakes, or model complex flock behaviour using simple rules of movement. Science Moves consists of several events, happenings and flashmobs in which science is crossed with bodily understanding.

As a participant, you will pretend that you are an object in a scientific model. For example, an atom, a neuron, a star – it all depends on the model. We have collaborated with scientists in specific areas to make games, where the rules determine how you are allowed to move. Together, you, the rules, and all the other participants become a scientific model – a human simulation.

The activities are called kinesthetic exercises, and support "learning by doing" with a healthy combination of movement and thought. Playful and unforgettable, they permit you to ask relevant questions to the models – and some times these questions lead to new knowledge.

[f] Synes godt om   Del 0

Organizer

Department of Science Education, Faculty of Science, University of Copenhagen

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✓ Synes godt om Du synes godt om dette.

Science in the City
1. juli

'Science in the City was here - slut på en mega succes eller?'

Mette blogger om forløsningen og tomheden efter et brag af en science festival + en kærlig opfordring til at udnytte succesens momentum!

Se oversættelse

Se oversættelse

Department of Science Education, Faculty of Science, University of Copenhagen
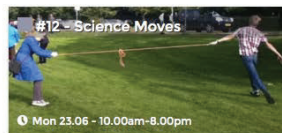
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UNIVERSITY OF COPENHAGEN

Workers at the Department of Science Education do research on and develop science teaching and communication. Subjects include biology, computer science, the geosciences, exercise & sports, physics, chemistry and mathematics.
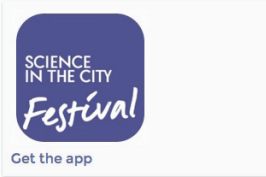
The Department caters to all education levels, but maintains a special focus on the second (for example, high school) and third levels (for example, university).

Furthermore, research is conducted on learning in informal learning enviroments such as museums and science centres and possible connections between such environments and learning in school and university settings.
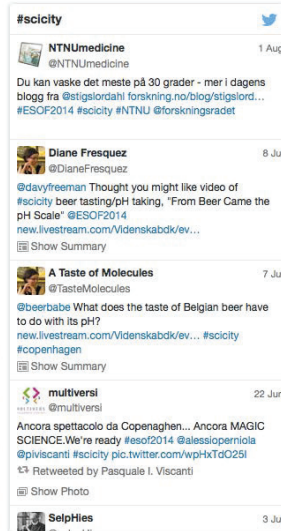
Related events

#12 - Science Moves
⏱ Sun 22.06 - 10.00am-8.00pm

#12 - Science Moves
⏱ Mon 23.06 - 10.00am-8.00pm

#12 - Science Moves
⏱ Tue 24.06 - 10.00am-8.00pm

#12 - Science Moves
⏱ Wed 25.06 - 10.00am-8.00pm

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APPENDIX C

19

Tricking Plants to Cure Cancer

Learning goals

Participants should
- enact the production chain for forskolin in a relevant plant cell,
- illustrate the reason why the natural cell does not produce a lot of forskolin,
- make suggestions as to how one could change "internal communication" in the cell to facilitate the creation of more forskolin, and finally
- enact the new situation.

Short description: Participants play the role of enzymes in the cell. Light, energy-storing molecules, DNA, mRNA, and products (forskolin) are represented with balls, sticks, and Velcro. The main part of the activity is to enact how the different co-dependent processes occur in the cell.

Time	Activity	Comment
00:00-10:00	Welcome and Part 1a	Warm-up and setup
10:00-40:00	Part 1: How drugs are produced in a normal cell	Setting up, let people figure stuff out + questions
40:00-45:00	Part 2a: Suggestions for optimizing drug production	Getting models and questions from participants
45:00-55:00	Part 2b: How scientists trick plants to optimize drug production	Illustration of "the solution" + questions
55:00-60:00	Feedback and Farewell	

Introduction: The script
Say: "In this exercise, we are going to illustrate some of the processes that happen, when a plant produces a substance that medical doctors use to treat several diseases, like eye diseas-

es and cancer. The substance is called forskolin. The problem is that the plant does not produce very much of the drug, so we need to harvest a lot of plant material, just to get enough of the compound for a few treatments. So here, we will see, why the plant cell does not produce very much forskolin, and we will use this knowledge to figure out ways to make the plant cells produce more forskolin. "

Part 1: How a drug is produced in a normal cell of a particular plant

Part 1a: The setup and the players

Say: "To get it all started, we'll set up a simplified plant cell. You will play the roles of some of the workers of the cell, the enzymes. The enzymes we're going to worry about live in the cell and make or do stuff. Since we're interested in very specific things, we will leave out other things. For example, we will only worry about three places in the cell. The first place is where the plant converts the energy of sunlight to chemical energy usable in plants. This place is called the chloroplast and we mark it with a green rope. The next place is where a lot of workers (enzymes) are located to help produce leaves, forskolin and even other enzymes. This is called the endoplasmatic reticulum, or ER. We mark this with a lot of blue ropes. Finally, we have the cell nucleus. This is where DNA, the blueprint of the cell, is transcribed into bits that are useful in the rest of the cell."

While this is said, we make and refer to the schematic cell that we are going to use during the activity. See Figure 1.
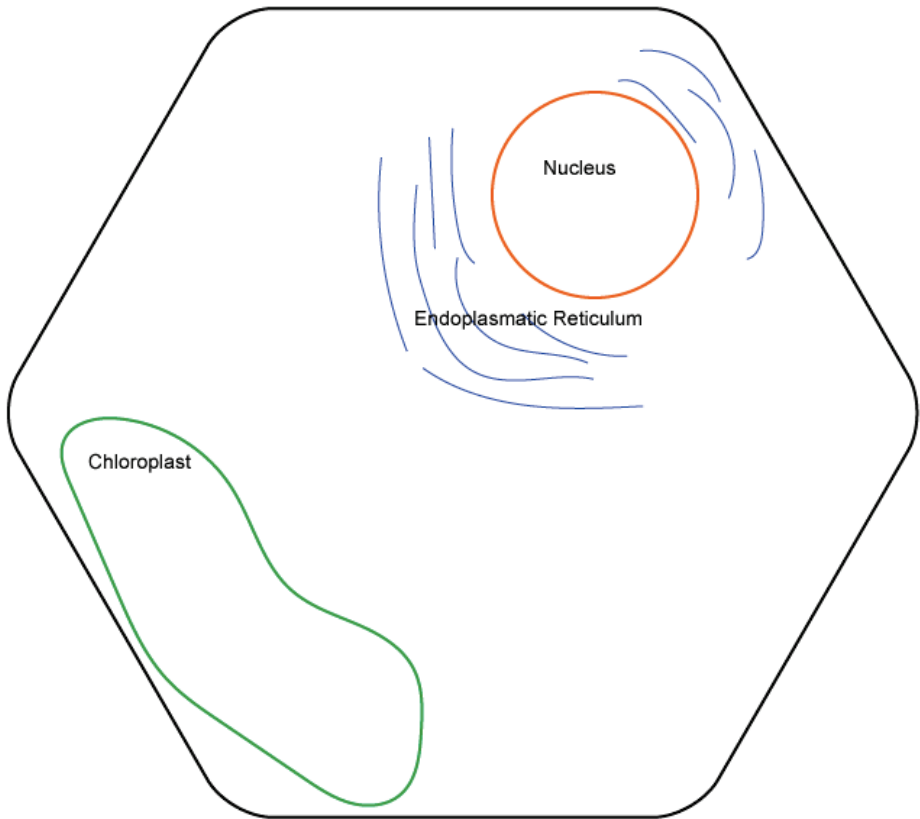
Figure 1. A schematic of a plant cell as we will construct it for the exercise. A more detailed schematic drawing is hung on the wall.

Say: "Now, let's visit each of the places to see what kind of workers inhabit them and what the workers work with. Before letting the simulation run, we go through each of the relevant cell-components to make sure everybody knows what to do"

The cast of workers is summarized in Table 1 below. Since the purpose of this activity must involve having people enact and engage with what enzymes do in the cell, all participants will represent enzymes. Other molecules, like non-enzyme proteins, DNA, RNA, and NADPH are represented with by other means.

Table 1. Participants will play the role of enzymes. Enzymes are located in a place in the cell. Place 1 is the location in the first exercise. Place 2 is the location in the final exercise. Function in the cell and kinaesthetic mechanism should match.

Enzyme	Place 1	Place 2	Function in cell	Kinaesthetic mechanism
NADPH Syntha-se	Chloroplast	Chloroplast	Produces NADPH from light and P	Light = red plastic balls P = purple plastic balls Sticks with two P on = NADPH
Ferredoxin (FD)	Chloroplast	Chloroplast	Electron donor	
ER Ribosome	Endoplasmatic Reticulum	Endoplasmatic Reticulum	Produce other enzymes	
P450-f	Endoplasmatic Reticulum	Chloroplast	Create forskolin	
P450-l - Leaf producing en-zyme	Endoplasmatic Reticulum	Endoplasmatic Reticulum	Build leaves	
P450-s - Seed producing en-zyme	Endoplasmatic Reticulum	Endoplasmatic Reticulum	Makes seeds	
P450-r-Root producing en-zyme	Endoplasmatic Reticulum	Endoplasmatic Reticulum	Makes roots	

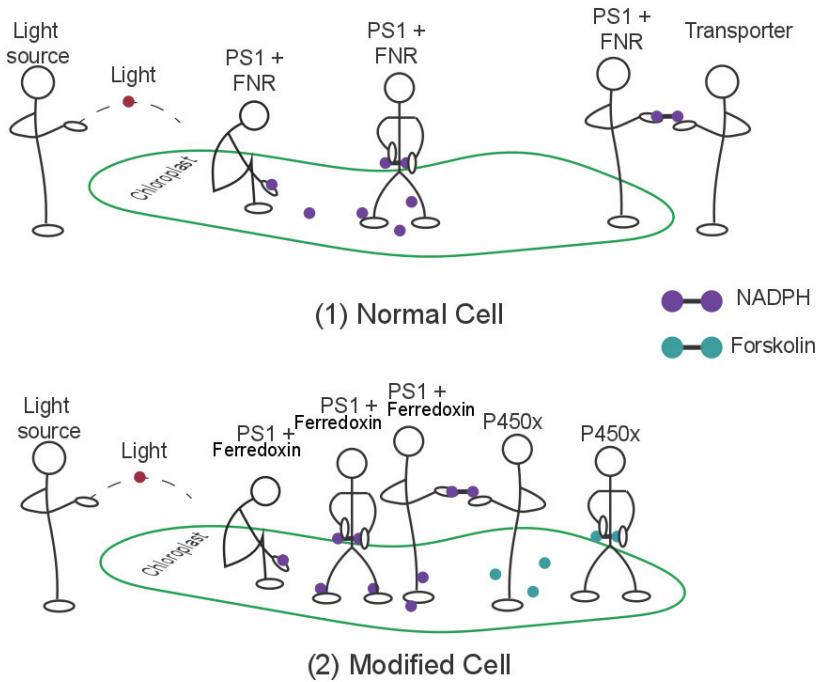| [Something] producing enzyme	Endoplasmatic Reticulum	Endoplasmatic Reticulum	xx	
Transporter	Chloroplast Membrane		Transports NADPH (energy)	
CPR	Endoplasmatic Reticulum	Endoplasmatic Reticulum	Uses NADPH	
Polymerase	Nucleus	Nucleus	Creates messenger RNA	

Part 1b: At the chloroplast: transforming energy

Figure 2: How the exercise represents the work of enzymes in the chloroplast in a normal cell (1) and in a modified cell (2). (1) is used in Part 1, and (2) is used in Part 2 of the exercise.

Say: "In the chloroplast, energy in the form of light is converted to chemical energy. The process is explained in the Chloroplast hand-out"

Do: Give the Chloroplast Hand-out to the people enacting the process. The hand-out describes the mechanism given below.

Mechanism for converting light to NDAPH: Sticks that represent NADP+, and balls that represent H+ lie in the Chloroplast. Persons inside the chloroplast represent the PS1+Ferrodoxin´NDAPH reductase enzyme. A person throws a red ball (representing light). If a

PS1+FNR complex catches the ball, the person may put a ball and a stick together. This ball and stick represents NADPH. The PS1+FNR then gives the NADPH to the *transporter*.

Part 1c: At the reticulum: Making enzymes and dividing resources
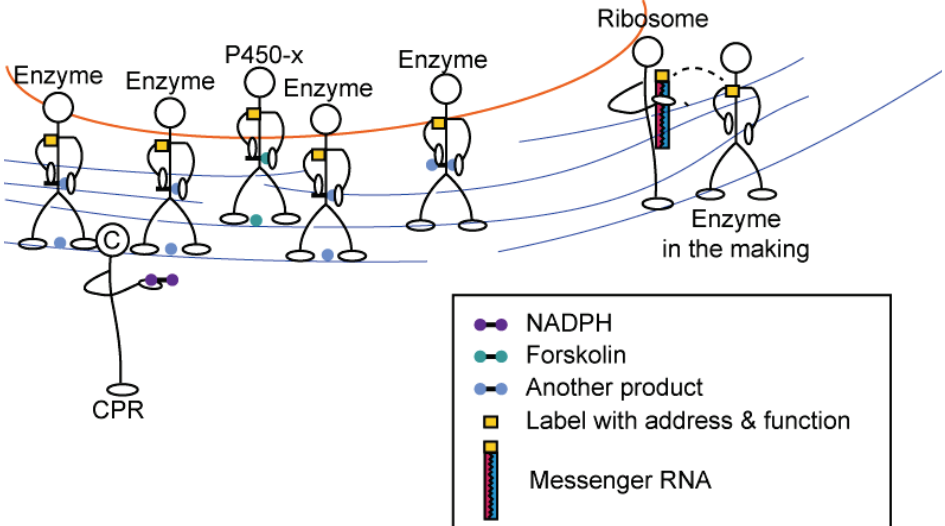
Figure 3: One participant is the controller, CPR. The controller distributes NADPH. An enzyme (e.g. P450-x) can make its dedicated product (e.g. forskolin) if they are given a stick with two purple balls (NADPH). They put the NADPH in their pocket and now have the energy to make the product. Ribosomes receive Velcro-DNA zippers (from the nucleus). They read the Velcro and write on the label.

Say: "In the ER, enzymes work to make different products. Some of the products are used to make leaves, others, like forskolin, is used as a defence mechanism. The worker enzymes are created by ribosomes. Ribosomes get their construction plans from the nucleus. Some of you will become enzymes, but you will have to be made before, you can begin working. When you are made, you will get a label, telling you what you are supposed to do, and where you are going to do it. The ribosome then writes a post-it note that says: "Type: [type of enzyme] Address: [address] Purpose: [purpose] Product: [product]""

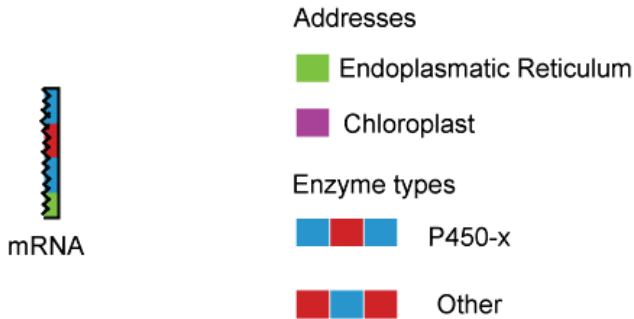*Figure 4: The reading scheme for ribosomes*

Mechanism for creating enzymes: When a ribosome gets an mRNA, the ribosome calls for a "pre-enzyme" participant. The Ribosome then uses the reading scheme (see Figure 4) to determine what kind of enzyme will be produced and where it should go. The ribosome then tells the enzyme: "The way you produce xxx is to"

> Put the [colour] balls on sticks. You will find the balls at your workstation. As long as you have the energy, you will produce xxx! You must call for energy by yelling out your purpose when you are not making your product".

Mechanism for making products: An enzyme can only make its dedicated product if it receives a stick of NDAPH with some candy inside. The participants take the NADPH–and put it in their pocket. After this, the enzyme constructs the product (e.g. forskolin as a stick with other coloured balls). If an enzyme is not constructing a product, the participant yells out their purpose, for example P450f would yell: "Defence!" The controller distributes the NADPH according to their wishes. The controller receives NADPH from the transporter.

When P450f makes forskolin it then throws it to the membrane and hits an insect who chews it and goes away.

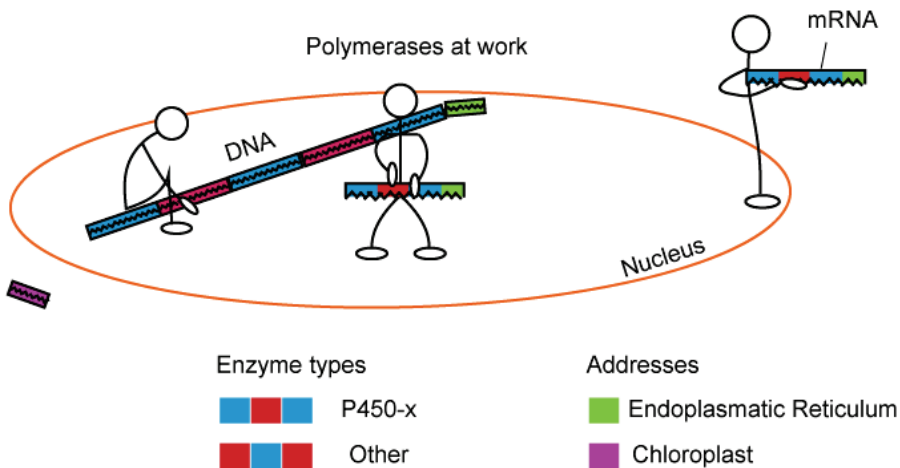Part 1d: At the nucleus: Producing enzymes

Figure 5: Participants enacting polymerase in the nucleus. The process of transcribing DNA to mRNA is enacted with Velcro with different colours. A black DNA Velcro is opened, and a white mRNA Velcro is attached in half of the DNA, and copied relevant information - This information is attached to the Velcro.

Say: "At the nucleus a lot of stuff is going on. But we need only concern ourselves with the enzymes that work to create messages (mRNA) for the ribosome. The enzymes make RNA and they are called RNA polymerase."

Mechanism for making mRNA: The participant unattaches the relevant Velcro's. And attaches another Velcro with another colour. The "postal codes" are copied from the DNA to the mRNA. Each piece of mRNA is transported to the ribosome. Each piece encodes a different P450-x.

Part 1e: Making the clock tick

Now, distribute everybody, and let them work out how they enact their function. Answer questions and so on. After a while:

Say: "Ok, now we want to see if we can make this clockwork tick. So now, let's start with light entering the chloroplast and enzymes being created at the nucleus."

Let people do their thing and see how it goes. Let it run a few times, and answer questions when they arrive. This is where people should really get to understand the process.

Part 2: How drugs are produced with synbio - creating a short-circuit

Part 2a: Ideas for producing more drug

Ask participants: "Come up with idea to make the cell produce more of the drug we want. "

Carefully evaluate each idea and list some of the promises and problems scientists would encounter if they used the idea.

Part 2b: Changing the address: bombardment of new DNA-bits

Say: "The way that scientists at KU (Center for Synthetic Biology) have done this is to change the postal address for the enzyme P450-f so that it goes directly to the chloroplast. Remember, as long as there is energy, P450-f will produce forskolin. The way, it all starts is by bombarding the cell with modified DNA. So instead of only having green Velcro's, with grey postal codes, we now also have green Velcro's with pink postal codes."

Now, the simulation is run again. The P450-f's go to the chloroplast and now have access to more energy. We may even have them be close to the PSI+Ferredoxin complexes.

Mechanism for bombardment: Instead of having green Velcro's with grey postal codes that represent the part of DNA that encodes for P450-f, we attach a different coloured post code, and throw the new ones in the nucleus.

Synthetic Biology Activity Sheet: At the nucleus

Overall goal with simulation: As a cell, we want to produce a number of molecules of forskolin.
Your function: You represent the enzyme that reads DNA and uses it to create building instructions for other enzymes. The construction messages tell the constructor enzymes to build particular kinds of enzymes.
Your name: Polymerase
How you do it

1. Look at the construction plan (below) to find out which building instruction to produce next.
2. Take a white strip and Find the place at the DNA string to transcribe from.

3. Copy the colour bands from the DNA to the white strip.
4. The white strip with colour bands on is the building instruction. Also called *messenger RNA,* or mRNA.
5. Send the mRNA to the edge of the nucleus.

Building sequence:

Leaf	Defence	Leaf
Leaf	Leaf	Roots
Roots	Defence	Roots
Leaf	Roots	Roots

Writing scheme:

Colour	Meaning
grey/pink	Address: ER/Address: Chloroplast
	Purpose: Leaf Produce: Leaf building blocks
	Purpose: Root Produce: Root building blocks
	Purpose: Seeds Produce: Seed building blocks
	Purpose: Defence Produce: Forskolin

At the ER: making other enzymes

Overall goal with simulation: As a cell, we want to produce a number of molecules of forskolin

After simulation: Compare how much other stuff we have produced and how much energy was used.

Your goal in the simulation: Translate building messages to produce other workers.

Your function: You represent the enzyme that translates building messages, also called mRNA. The construction messages tell you what to build.

Your name: Ribosome

How you do it
1. Look at the building instruction (the white strip)
2. Look at the translation scheme (below)
3. Write a post-it to tell the newly produced enzyme:
   a. where to go (the address)
   b. what to yell out (the purpose)
   c. what to produce (the product)

Translation scheme:

Colour	Meaning
grey/pink	Address: ER/Address: Chloroplast
	Purpose: Leaf Produce: Leaf building blocks
	Purpose: Root Produce: Root building blocks
	Purpose: Seeds Produce: Seeds building blocks
	Purpose: Defence Produce: Forskolin

At the ER: being a worker enzyme

Overall goal with simulation: As a cell, we want to produce a number of molecules of forskolin

After simulation: Compare how much other stuff we have produced and how much energy was used.

Your goal in the simulation: To make one particular molecule

Your function: You represent one of the types of enzymes that produce different kinds of molecules that the cell uses for growth and defence.

Your name: Whatever is written on the post-it

How you do it
1. When produced, you will receive a sticker (post-it) with information on where to go, what to yell, and what to produce.
2. Once produced, go to the place you have been assigned
3. Yell out what you have been instructed to yell out.
4. If you receive energy, break it apart to retrieve the treat.
5. Use the stick to produce one molecule of the kind you are supposed to produce. See schema below.

Enzyme	Product	How it looks in the simulation
Leafbuilder	Leaf building blocks	
Rootbuilder	Root building blocks	
Seedbuilder	Seed building blocks	
Forskolinbuilder	Forskolin	

At the ER: distributing energy

Here are instructions for working as an enzyme that distributes energy to other enzymes in the Endoplasmatic Reticulum, or ER.

Overall goal with simulation: As a cell, we want to produce 10 molecules of forskolin

After simulation: Compare how much other stuff we have produced and how much energy was used.

Your goal in the simulation: To distribute energy storing molecules (NADPH)

Your function: You receive energy molecules and give them to the enzymes that work in the reticulum

Your name: CPR

How you do it
1. Get energy from Transporter
2. Give it to the enzyme that captures your attention

Between the Chloroplast and the ER
Here are instructions for working as a transporter between the chloroplast and the ER.

Overall goal with simulation: As a cell, we want to produce a number of molecules of forskolin
After simulation: Compare how much other stuff we have produced and how much energy was used.

Your goal in the simulation: To move energy (NADPH) to ER.

Your function: You represent how NADPH is moved from the chloroplast to the ER.

Your name: Transporter

How you do it
1. When energy is put at the boundary of the chloroplast, take it.
2. Carry it to the CPR.

Synthetic Biology Activity Sheet: At the Chloroplast, making energy
Here are instructions for working as an enzyme in the chloroplast that transforms light into chemical energy.

Overall goal with simulation: As a cell, we want to produce a number of molecules of forskolin
After simulation: Compare how much other stuff we have produced and how much energy was used.

Your goal in the simulation: To make energy storing molecules (NADPH)

Your function: You represent the workers that make chemical energy out of light.

Your name: Photosystem 1

How you do it

1. Catch a light particle (red ball).
2. Put a treat in one purple ball.
3. Put the purple ball on a stick with another purple ball in the other end of the stick.
4. This is the energy storing molecule, NADPH
5. Leave the NADPH at the boundary of the Chloroplast.

Electric Motors

Learning Goals

Participants will:

- use the Lorentz force law for single electrons in a magnetic field to enact human movements that correctly represent electron movements in a magnetic field.

- understand how a motor transforms electric energy into kinetic energy

- navigate in a state-space; relate position to velocity to force

- try different strategies to control the state of the motor, to get from an initial point to a target

- try to find an optimal strategy and understand what the algorithms behind do

General Script

This project is a collaboration between the Department of Science Education and researchers in different fields and research institutions. In this specific one, we have collaborated with Esteban Fuentes, a PhD student at the University of Munich to create movement exercises to promote learning and new insights. It is not so usual that we use kinaesthetic representations of knowledge, but they can bring us new questions, greater engagement and fun, too! This is work in progress, and these workshops work differently with each group.

Introduction: The Script

Say: "Today we're going to learn about physics and engineering. How can we use magnets and currents to create a motor? Where are such motors used? How can we make computers control the speed and position of the motor? How do computers think about these things and how do we control the motor, how do we make sure the computer does control the motor in an optimal way?

First, we will find out how electricity and magnetism can make things move. Then we will use this to find out how we can make an electric motor that could be used for example in a 3D print-er. Finally, we will see how we can control and optimize control of that motor, so that we can make quick and precise movements."

Exercise 1: The interaction between moving electrons and a magnetic field.

Purpose: The participants will enact magnetic fields, moving electrons and the Lorenz-force law when there is no electric field.
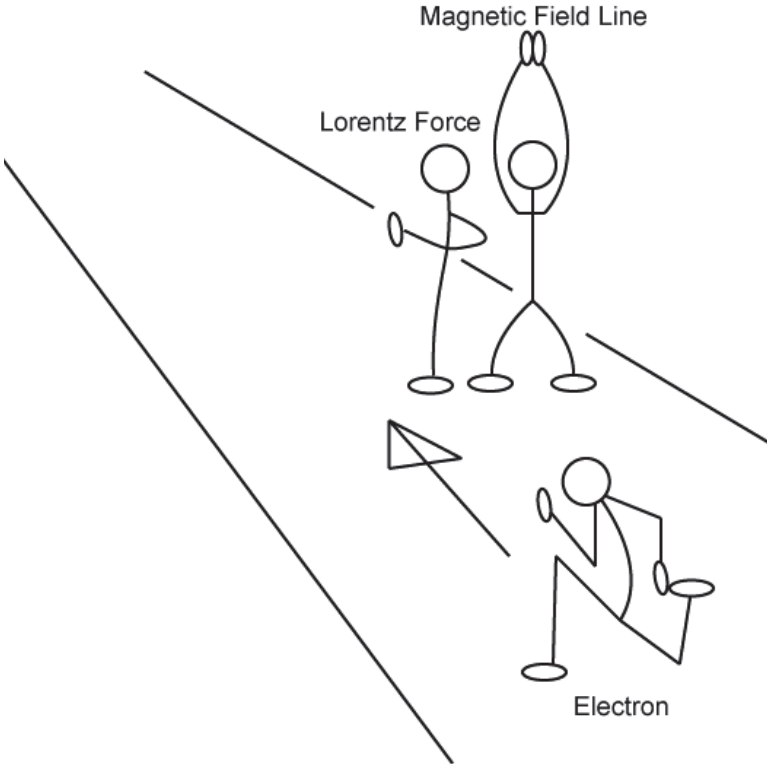

Figure 1: Participants enact the Lorenz force law. One is the magnetic field. The other is the moving electron. The force acts (slight push) when the electron passes. Bigger magnetic field (more extended arms) equal bigger push/force. Higher velocity (faster pace) equals bigger force.

Setup: Groups of three. One participant enacts an electron, one a magnetic field line (MFL), and one the Lorenz force.

Mechanism:
- Electron-participants move straight with a constant velocity unless affected by a force.

- MFL participants can point up. The length of the person relative to his/her full height corresponds to the magnitude of the magnetic field.
- Force-participants push on moving electrons if they pass them from the left (and magnetic field is upward). They push harder if electrons run faster. They push harder if MFL-participants increase their height.

These things are explained beforehand. Especially the Lorenz-force law is introduced as a fundamental and strange law of nature.

Activities:
- Electrons run straight with no magnetic field.
- Electrons run in from a different angle or side.
- Flip the magnetic field (people make a hand stand)

Remember to switch roles, so everybody gets to be electrons, magnetic fields and forces. Remember to answer questions and explain as we go along.

Sum up/segue:
So electrons moving in a magnetic field will experience force. Let's constrain the electrons to moving in a wire, and see if we can make the wire move.

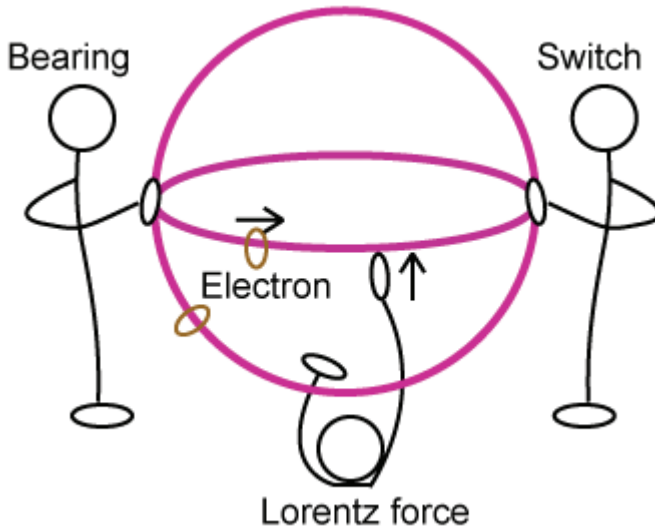**Exercise 1b: Making a hula-hoop motor.**

Figure 3. The hula-hoop motor consists of two hula-hoops perpendicular to each other. Electrons are marked with tape. The switch marks that it is turned on (a hoop) by having both hands on the hoop. A fourth person (not shown) makes sure the electrons move (for example, in the direction shown). The Lorentz force person lies on the ground and pushes upwards/pulls down on any electron passing.

Purpose: Participants collaborate to enact the setup and function of an electrical motor.

In groups of four with one double hula-hoop (with tape loops signifying electrons); participants now enact a simple electric motor.

Say: "The double hula-hoop represents two electric wires, and the loops of tape represent electrons. If a current is running - that is if electrons are moving in the wire - and we apply a magnetic field, then a force will act on the electrons in the circuit. Let's try it out!"

One person (or more) enacts the bearing.
One person (or two) moves around with the electron(s)
One person (or more) lies on the ground and enact the force due to the interaction between the electron and the magnetic field.

Finally, one person is the switch. When the switch's hands are on a wire, the current runs. If the wire turns too much, the hands must find the other wire (the other hula-hoop).

Task: What happens when the switch is turned on (and the current runs) if we apply a constant magnetic field? (The loop begins to turn)

What happens if the current is reversed? (Turns the other way)

What happens if we do not use the second hula-hoop? (Motor stops)

What happens if we let go of the bearings? (The motor breaks apart)

What happens if we increase the current? The magnetic field? (The motor turns faster)

Summing up: "So we can control a motor by applying more or less current in different directions. We can make it go faster, but if it goes too fast, it may break. "

Exercise 2: Controlling magnetic motors

Exercise 2a: The connection between state space and the electric motor
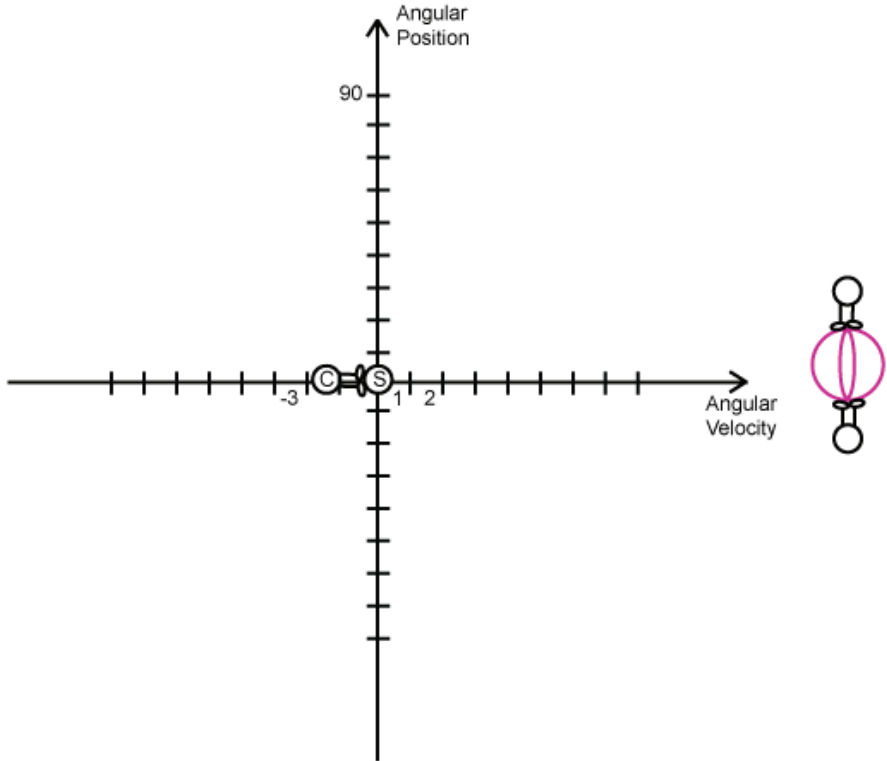

Figure 4. Representation of state space. The axes will be marked with tape. The ticks mark lanes in which the state marker can move. The state marker is represented by the circle with an S. The controller, who can push the state marker, is marked with a C. Once in a lane (say lane 1), the state marker moves with speed 1. In lane 2 with speed 2. In lane -3, with speed -3. To the right are two participants with a hula-hoop motor, they represent the movement of the real motor by turning the hula-hoops.

Purpose: Participants enact the computerized controller that operates on a state in state space. At the same time, they see what the state space corresponds to in reality.

Say: "Engineers want to create computers that can control the motor. The computer needs to be able to think about the (angular) position and velocity of the motor and also the amount of electricity it needs to provide to make the motor go faster or slower. When scientists think about how computers think, they sometimes draw two lines that are perpendicular and say that velocity is on one line and position is on the other line. This is a coordinate system, and with that we can visualise how a computer's brain thinks about motors. What we want to do in a little while is to make a script that tells the computer what to do to reach a certain position. First, we need to understand how the computer thinks!"

Setup/Mechanism:
One person represents what the computer thinks about the motor. That is what the velocity and the position is. (The state person).
Another person is the controller. This person represents what the computer does.
Two other persons enact the motor. They need to turn the hula-hoops to show states.

Moving in state space. The state person moves according to which lane the person is in. In lane 1, the person takes very small slow-motion steps. In lane 2, larger steps but same pace. In lane 3, larger steps still, but same pace. In the lanes, we mark how large the steps should be.

Task:
Before we start the motor and turn on the computer, we turn the motor to an angle. Show this is in the coordinate system.
Now, we turn on the motor to the smallest speed. Do this by having the controller push the state person out the velocity=1 lane. What happens in the motor?
What happens in the motor if the state person is moved to the 2 or 3 lanes?

Sum up: "Now, if we want the computer to be able to reach a particular angle and then stop, we need to tell it how to do this. It could be because when we have reached this angle, we have lifted something we wanted to lift a certain distance."

Exercise 2b: A simple algorithm to reach a particular angle
Say: "Scripts have the form like this: Check if your are at the angle. Check if you are moving. If you are at the angle, lower speed by 1. If you are not at the angle and not moving, increase velocity by 1. If you are not at the angle and moving, do nothing"

Setup/Mechanism: As before, but now the controller acts according to the script.

Task: Make a script that lets you reach an angle of 90 degrees.

Sum-up: "The script you have created is also called an algorithm. Of course the computer needs to check with the real motor, if the angle has been reached. Then it needs a sensor. For the next exercise, we will skip the part of the sensor, and then we really don't need the hula-hoop motor."

Exercise 3: Optimizing motor control

Purpose: Participants should design an algorithm that they enact in state space. The algorithm should represent the fastest way to reach an angle of 270 degrees from 0 degrees.

Setup/Mechanism: As before, but the two other participants either act as controllers or checks that the algorithm is enacted properly and observes how it works. They record the time it takes to reach the angle.

Hand-out: Pieces of paper with algorithms written on them. A couple of different algorithms should be made available.
Say: "Now, your task is to choose an algorithm, enact it and then make suggestions for im-provement. You can also make your own algorithm from scratch. "
Task: Find the algorithm that lets you reach 270 degrees fastest.
Sum-up: "Let's see what kinds of algorithms you guys found out. The optimum algorithm in a real motor is (show it). Finding this took four years of research!"

....
Extra:

Magnetic field line (MFL) participants are equidistantly distributed in a square (or rectangle, or line) in one part of the room. Each MFL-participants is grouped with one Lorenz-force partici-pant.
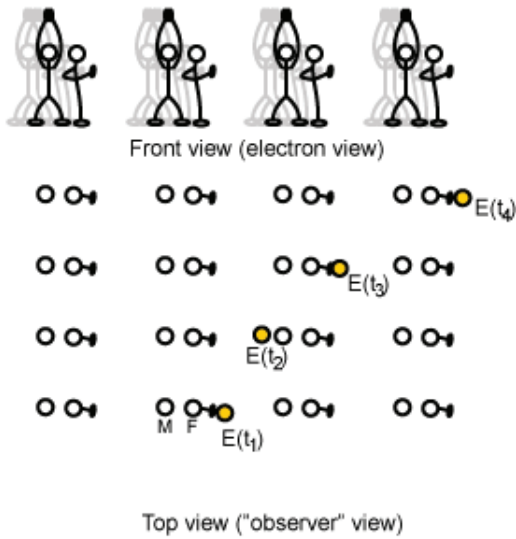
Front view (electron view)

Top view ("observer" view)

Figure 2: A magnetic forest consisting of pairs of magnetic field lines (M) and Lorenz force enacters (F). Electrons move into the forest and becomes pushed. Important to enact that electrons only change direction when pushed by Lorenz force enacters.

- Electrons run into line of uniform magnetic field lines.
- Electrons run in to a forest of uniform magnetic field lines.
- Electrons run in to a forest of varying magnetic field lines.

Past Disasters

Learning Goals

Participants will

- simulate how researchers can get information about past disasters and their influence on different aspects of human society and development
- experience the difference between a simulation of real events and representing findings about events as data.
- enact and reflect upon the impact on extreme geophysical events on human societies.

Introduction: Script

Disasters happen in the intersection between geophysical events and the communities affected by them.

Therefore, we need to study the communities too.

We focus here on the networks and interactions between the communities.

We can learn about the previous vulnerability of communities from their survival after the events.

Disasters can show us the previous vulnerabilities of the communities. They can be seen as catalysers, rather than the causes.

It is all so long ago, that all we have access to are the material pieces.

Time	Activity	Comment
00:00-20:00	Welcome and Part 0: setup	Define landscape
20:00-25:00	Part 1: Before the disaster	
25:00-35:00	make records	
35:00-37:00	Part 2: Disaster	Make changes to landscape
37:00-42:00	Part 3: After the disaster	

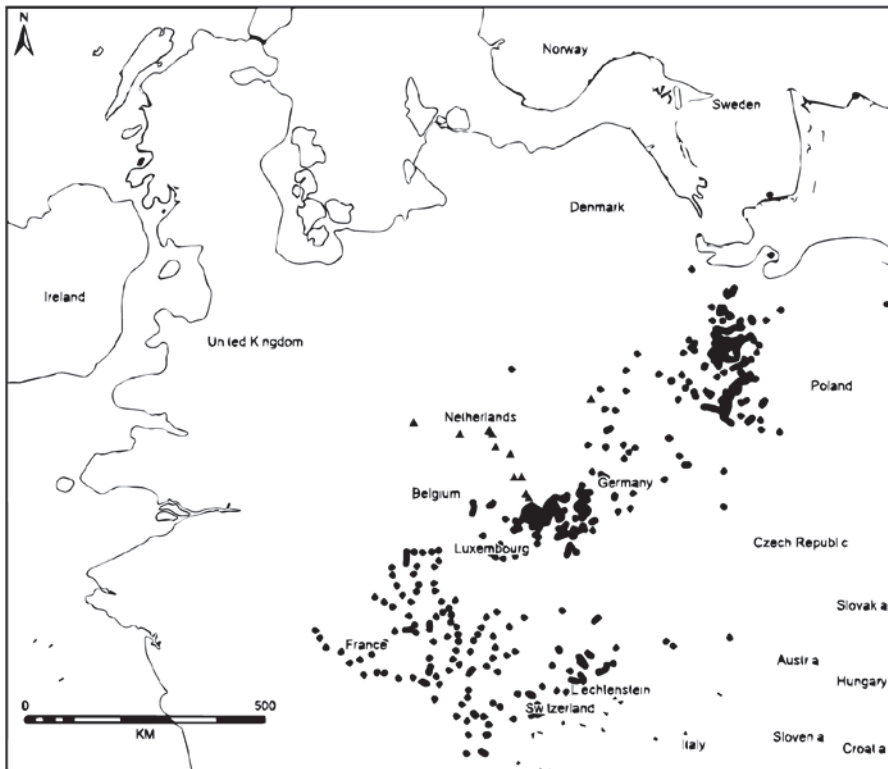| 42:00-52:00 | make records | |
| 52:00-60:00 | Feedback and Farewell | |

Part 0: Setting Up

Figure 1: Set up a map based on Europe as it was at the time of eruption. The lines above would be represented by rope. Structures within the lines (lakes, mountains, icecaps, etc.) would be marked with more ropes, cardboard boxes and tape. So the map above will be recre-ated in the room we use.

Here participants and facilitators set up the map (see Figure 1). We use the whole room and mark rivers, plains, lakes and mountains. This is done using rope, tape, and perhaps pillows and/or cardboard boxes.

A direction is chosen so that North, South, East and West is represented.

According to the landscape and direction, we now distribute resources on the simulate landscape. Resources are represented with Lego, and they are described in the Past Disaster Spreadsheet.

For each different type of landscape, facilitators declare rules for movement. See Table 1.

Table 1: Landscapes and the movement type.

Landscape Type	Movement
Mountain	Slow movement (only very small steps)
River	Instant movement (the largest set of steps)
Plains	Medium movement
Lakes	Medium movement
Shore	Medium movement
??	??

We instruct people that 1 second in this simulation is 100 years (or something), and that one step is x km. Thus time and movement are sort of abstract.

Part 1: Before the extreme event

This part is two-fold. First we have participants simulate large scale human behaviour by having them act as if they were a People (community, tribe, culture…). Then we stop the simulation and have them draw a map from the evidence of their behaviour that is left behind in the simulation landscape.

Part 1a: Simulating large scale human behaviour in a landscape

In this part of the simulation, people move around in the simulated landscape. They trade, invent, carry some stuff with them and leave other stuff behind. In short, they create traces of

human activity. To facilitate this simulation, we have created some rules and definitions. First, we want the participants to represent Peoples that inhabit the landscape.

To leave traces of human activity behind, we need some way of simulating human interaction with the natural resources and with each other. To this end, we have included different kinds of resources, inventions and constraints on behaviour.

There are different kinds of *natural resources*: FOOD, "JEWELRY" and "TOOLS". Each is represented by a shape of Lego. Sub-types may be represented with colours.

An *invention* is made when a participant puts pieces of Lego together. Different natural resources may be put together. There are no rules for how much stuff may be put together.

In this simulation, a People can only *trade*, *invent, move, carry stuff or leave stuff*.
- 2 Peoples who are close to each other can *trade*; exchange items based on mutual agreement. The actual interaction is left to people themselves. This may result in some kind of role-play, but we should emphasize that the simulation does not contain war.
- A People can put together whatever natural or processed resources they possess. This is *inventing*.
- A People may *move* around on the map with small steps (their speed is determined by the landscape, see Table 1.
- *Carrying stuff*, a People is limited to what they can actually carry.
- *Leaving stuff* behind makes it available to whoever encounters it.

A people consume FOOD resources when they move.

Part 1b: Tracing human activity on a map of the landscape

After the simulation has run for five minutes, facilitators use a verbal cue to stop the simulation. Participants leave all inventions and resources they are carrying exactly where they stand.
Now we turn to a pre-made map of the landscape. It could be a large copy of Figure 2, if Figure 1 has been used as a model for the landscape. Now we tell them, what kinds of LEGO they may draw on the map. We have pre-defined what resources (that is what LEGO pieces) and parts of inventions may be observed. The point of this is that if an invention has been built by a resource

that lasts and another that does not endure time, participants may only record the lasting re-sources on the map.
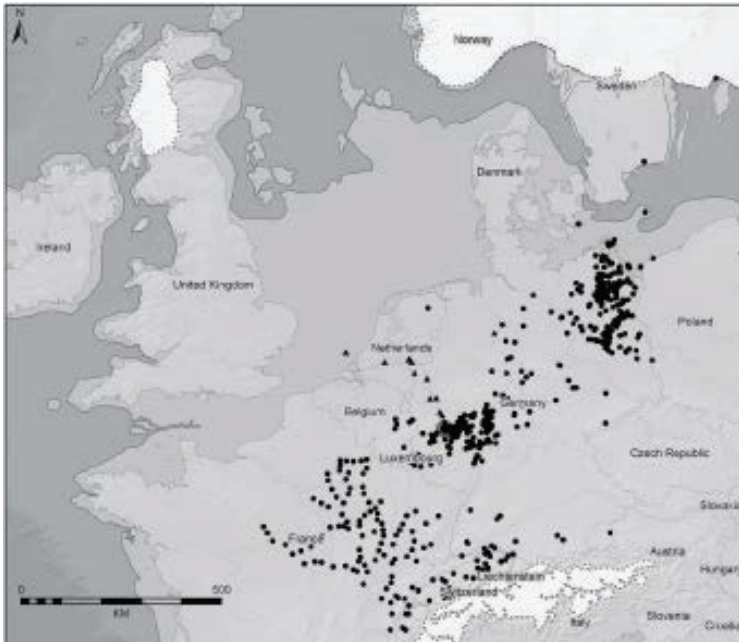

Figure 2: The map we want participants to draw their findings on.

Part 2: The extreme geophysical event

Now, we play a disaster-sound (maybe the sound of an erupting volcano). Then we, facilitators and perhaps participants, change the landscape in the following way: We make a new land-scape type, called "Ashen land" (or something), and overlay it on different parts of the simulated landscape. Ashen land contains no natural resources and cannot be inhabited. . Also, we might change other landscape types, because of other effects (climate change, etc.). Things left in Ashen land are inaccessible to Peoples.

Part 3: After the extreme Event

Basically the same as Part 1. First we have participants simulate large scale human behaviour by having them act as if they were a People (community, tribe, culture…) in the new landscape.

Then we stop the simulation and have them draw a map from the evidence of their behaviour that is left behind in the simulation landscape.

Part 3a: Simulating large scale human behaviour in new landscape

Same as Part 1a, but with some changes in movement behaviour due to new landscape and changes in People behaviour due to the disaster event. The changes in People behaviour should be evident from their People card.

Part 3b: Tracing human activity on a map of the new landscape

Same as Part 1b, but resources and inventions that in Part 1a where left in what became Ashen land in Part 3a, react differently to time than other resources and inventions. Discussion of the outcome.