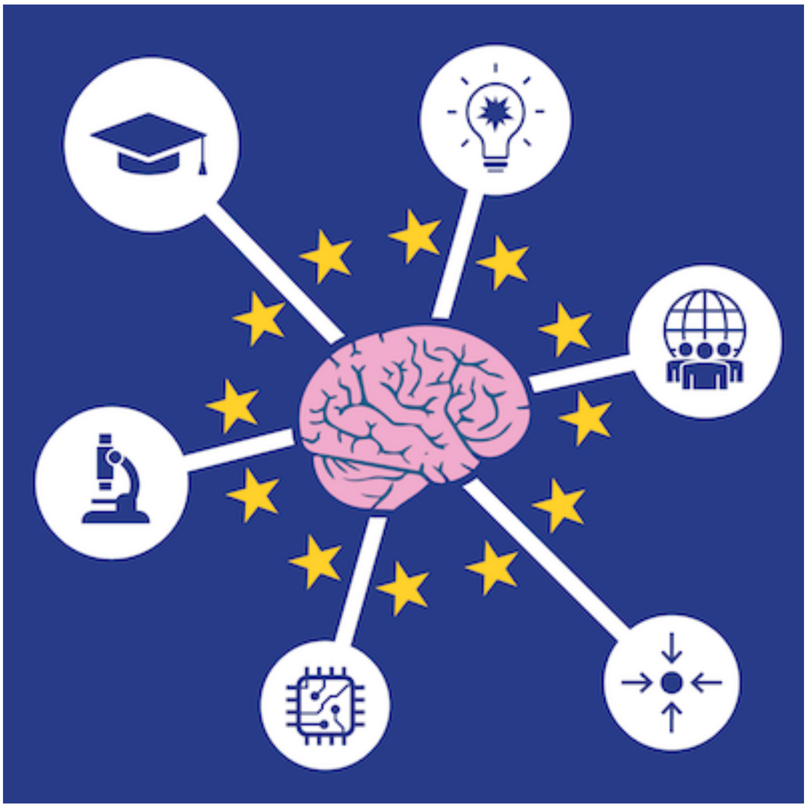
Neurotech^EU

The European University of Brain and Technology



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This deliverable was achieved in collaboration with all consortium partners. The NeurotechEU Summit 2022 took place on September 12th and September 13th combined with a summer school. In September 2022, Radboud University organised the Donders Cognition, Brain, and Technology (DCBT) Summer School in Nijmegen (https://bcbt.specs-lab.com/bcbt22/). The school took place from September 4th – September 16th, and in total, 15 students (Master's and PhD) participated in this summer school, in the framework of NeurotechEU. They followed a two-week intensive programme, including lectures, tutorials, and project work. This was in collaboration with students from other EU-funded projects.

This edition of the NeurotechEU Summit focused on the eight dimensions of neurotechnology (https://theneurotech.eu/mission-vision/). This was selected as a suitable focus, as the coordination switched position between the previous summit and this edition from Tansu Celikel to Paul Verschure at Radboud University. Defining the dimensions was one of Paul Verschure´s first aims in setting the direction for the alliance. However, these dimensions were in need of further elaboration. This included, for example, the strengths and weaknesses of each dimension and the educational goals per dimension.
The final agenda contained 6 different in-depth discussions around the eight dimensions of neurotechnology. Furthermore, the agenda included several scientific lectures. The complete schedule can be found below.

Schedule NeurotechEU Summit September 2022		
Date	*Time*	*Topic*
12 September 2022	09:30-13:00	Lectures on Neurostimulation *Klaus Schellhorn & Ciska Heida*
	14:00-16:00	Dimension 1: Empirical & Clinical Neuroscience
	16:00-18:00	Dimension 2: Theoretical Neuroscience
	20:00-22:00	Dimension 5: Neuroinformatics
13 September 2022	09:30-13:00	Lecture on Visual Neuroscience and Technology *Mathew Self & Richard van Wezel*
	14:00-14:30	DCBT Guest Lecture *Timo van Kerkoerle*
	14:30-16:30	Dimension 3 & 4: Neuromorphic computing & control / robotics
	16:30-18:30	Dimension 6 & 7: Neuroprosthetics & Clinical neurotechnology
	20:00-22:00	Dimension 8: Neurometaphysics

During the summit, all partners were represented. Furthermore, NeurotechEU Student Council representatives, associated partners, experts, and stakeholders participated in the sessions. There were fruitful discussions around the different dimensions. Based on these discussions, a report has been designed. The goal of the discussions was not purely to reach a consensus, but rather to exchange different points of view, exposing potential opportunities and chances, but also risks and dangers. The full report is added to this document as an Annex.

Annex: The Neuroinnovations Summit 2 report.

NeurotechEU summit: Elaborating the NeurotechEU Content Space

September 12 & 13, 2022
Nijmegen, the Netherlands

Preamble

Moderator: Paul FMJ Verschure
Rapporteur: Pam Graave

This report reflects the discussions during the NeurotechEU summit on the 8 dimensions of Neurotechnology. The report does not claim to express a consensus but rather the different points of view that were exchanged. As such, it is the beginning of contributing to the NeurotechEU roadmap, which will be elaborated over subsequent summit discussions and ad hoc working groups.

We thank all participants for their active and constructive contributions, and it shows the potential of NeurotechEU (NTEU) in terms of education and research.

NeurotechEU summit: Elaborating the NeurotechEU Content Space

Monday, September 12, 2022

The goal of the summit discussion was to elaborate on the eight dimensions defining the Neurotech content space as described in the white paper "The Neurotech[EU] Content Space: An initial sketch"[1].

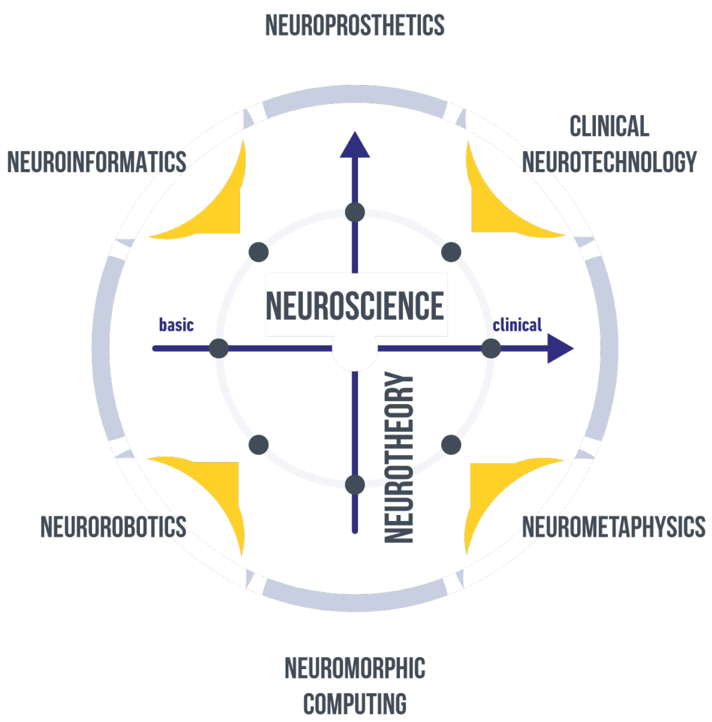

Figure 1: The eight dimensions of Neurotechnology

[1] https://theneurotech.eu/mission-vision/

Dimension 1 - Empirical and Clinical Neuroscience

Present: Lennart Verhagen, Timo van Kerkoerle, Peter Szucs, Christian Henneberger, Sandra Blaess, Sandra Jurado, Laura Frutos, Ed Waisanen, Maria José Such, Juana Gallar, Javier Castro, Can Yücesoy, Inmaculada Blaya, Necati Aras, Mathew Abrams, Joana Pereira, Oana Vanta, Cristina Iuga, Livia Popa, Minh Tue Ngo, Hector López Carral
Moderator: Paul Verschure
Rapporteur: Pam Graave

Presentation Necati Aras

It is important to understand the trends in extant literature. To help the consortium in this task, Necati Aras of Boğazici University (https://ie.boun.edu.tr/faculty/necati-aras-0) presented the bibliometric toolbox to have a quick overview or scan of the trends in the literature. This can give leverage to the different work packages. Content maps based on metadata/keywords/titles can be designed to define the domains that link to the dimensions we want to explore—in this way, building up clusters of concepts that fill out the neurotech dimensions.

We are in the position to define the field of neurotechnology. First, we can define the dimensions and associated keywords in general and then use the bibliometric toolbox later to refine. By this, we can elaborate on the content of every dimension. We first need to define the content domains and subdomains we can extrapolate into dedicated research programs.

The deadline for submitting phase 2 is March 2023 [note: this has been superseded by events. The call was published on 30 September, with the deadline of January 31[2]]. If we can identify keywords already, note them and share them with Pam Graave [email: pam.graave@donders.ru.nl]. Around October/November, we should have more details about the definition of the neurotechnology dimensions and concept clusters we will use in the roadmaps and the proposal.

SWOT analysis

What elements of neuroscience and neurotechnology should we consider in the profile of our future? To answer this question, we performed a SWOT analysis of the field of neuroscience. Overarching themes within the analysis are merged in the table below. Most SWOT aspects were recognized by everyone. The interference of industry and the introduction of new technology were debated.

[2] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/erasmus-edu-2023-eur-univ-1;callCode=null;freeTextSearchKeyword=European%20Universities;matchWholeText=true;typeCodes=1,0;statusCodes=31094501,31094502;programme=

Table 1. SWOT analysis. Analyzing the strengths, weaknesses, opportunities and threats of neuroscience and neurotechnology.

Strengths	**Weaknesses**
- Methods applied - Widely studied field - Experience in research - Emerging technology - Allows to think about the brain - Foundation of neurotechnology - Integration of different disciplines	- Lack of collaboration - Vague/broad - Lack of communication - Fragmentation in neuroscience - Ultra-specialization - Excessive reductionism - Data deluge - Ethics - Lack of translation to clinical application
Opportunities	**Threats**
- Ameliorate brain disease and improve on wellbeing - Open source - Intersectoral expansion - Technological development - Intersegmental expansion - Funding - Salvage teleology - Team Science - Easy exchange of knowledge - Lots of research potential	- Physics - Competition - Fake neuroscience - Slow development - Brain-drain - Isolation of the field - Big Technology - Lack of common vision and sustainability - Gaps in communication

<u>NeurotechEU's goal in education</u>

Various visions for education in neuroscience were presented:

- Train students in the overall theoretical framework of neuroscience;
- We should be bolder and strongly focus on what NTEU will do instead of remaining vague. For example, by working together with the industry;
- Teaching students how to collaborate and increase creativity;
- We must attract active people to support teaching;
- Involve different disciplines in training programs that contribute to the field and expose students to this multi-disciplinary perspective, so they have different ways of addressing challenges;
- We must integrate subdomains into larger frameworks;
- We should ask ourselves what the need is in society: deliver good scientists, caregivers, or something in the middle?;
- NeurotechEU must be clear about the foundations and make sure to teach basic neuroscience; students must know about the brain, i.e., the dimension Theoretical Neuroscience.

Dimension 2 – Theoretical Neuroscience

Present: Timo van Kerkoerle, Peter Szucs, Christian Henneberger, Sandra Blaess, Sandra Jurado, Laura Frutos, Maria José Such, Juana Gallar, Javier Castro, Can Yücesoy, Inmaculada Blaya, Necati Aras, Mathew Abrams, Joana Pereira, Oana Vanta, Cristina Iuga, Livia Popa, Minh Tue Ngo, Hector López Carral, Ton Coolen, Peter Hagoort
Moderator: Paul Verschure
Rapporteur: Pam Graave

Problem of neuroscience

It is crucial to define the core challenge of foundational neuroscience, which is explained in the introduction of Dimension 2: Theoretical Neuroscience. People generally collect enormous amounts of data, but this does not guarantee insight and theoretical unification. We should specify the theoretical frameworks and main challenges that allow us to organize the data we collect and guide future data collection. For education, this could mean creating a theoretical mindset to give people time to reflect on the central questions instead of immediately jumping into the empirical world afforded by technology.

Collaboration among multiple disciplines

We are in a time where physics and biology can be brought closer together in research. Being an expert in both disciplines does not result in being the best scientist. We must think differently in multidisciplinary work and have a **common language**. From a long-term perspective, we should get the best people to collaborate and form synergies instead of providing services to each other.

Collaboration with physicists is already taking place at some level and can be helpful to open new doors in neuroscience and pose questions more precisely. Conversely, psychology and cognitive science cannot be ignored with their questions about the function of the brain and the nature of the mind. The next generation of students will need Ph.D. programs, which also provide skills that enable them to develop basic algorithms and use programming languages and advanced AI techniques instead of only anatomy and physiology. The problem is that currently, there is no space to focus on the curriculum to achieve these integrative goals. Methods must be developed to alleviate this challenge. For instance, students can give each other additional lectures from different disciplines.

Neurotheory

Interestingly, if we push to the discussion of fundamental challenges, we move to psychological questions. If you think about such big questions, it is about how physical systems can give rise to volition and consciousness or from atoms to qualia. Theory can help us address these questions about the mind and subjectivity or first-person states from a third-person perspective. It is about training the next generation of researchers in a mindset of crossing the barriers between the physical and non-physical domains from life sciences to engineering and cognitive science. We have fundamental biological questions, and we need to consider the biological perspective to answer the big questions about the brain. Access to first-person states hopefully allows us to make the fundamental questions more accessible in a verifiable third-person form. We know that we have to bridge physics, biology, and psychology, but we don't know yet how and what the underlying principles are. Such lacking specifications challenge the ability to develop and deploy technology.

<u>**Core ingredients of Neurotheory**</u>

- Some attendees proposed to start with **anatomy and physiology**, including some **cell biology**. NeurotechEU students need to know the basics. *Or do we assume that they already have this beforehand?* In parallel, we need to help students understand **brain models, learn how to program, and look at analysis tools** by training the students through the modeling of neural systems in various contexts.

- All attendees agree to bring in theoretical frameworks such as **information theory** early in the curriculum. Information theory would be a toolbox for analysis and advancing theory because it makes you think differently about processing systems. A suggestion is to start with the four questions of Tinbergen, the three levels of Marr, the new synthesis in evolutionary biology with its multi-scale perspective, and systems theory for students to understand the history of this field and develop a systems perspective on mind, brain and behavior, and its associated technologies.

- The question why not include **machine learning/deep neural networks** was posed. It may not be the primary content in such a curriculum, but when you explain the operation of a neuron to show how this has inspired avant-garde algorithms in AI is a relevant elaboration. Yet, being mindful of distinguishing neural metaphors from neural reality. The counterarguments are that what happens in deep learning machines is nothing new and not a recent intellectual achievement. Rather, the neurotechnology dimension of Neuroinformatics could have machine learning as a tool that people can use for signal processing and help classify, compress, and comprehend data. Still, it is not necessarily a part of the theory that seeks to explain how brains work. Hence, machine learning techniques seem better placed in Neuroinformatics.

- *What is missing in neurotheory? Do we want to include biomechanics?* **Biomechanics** would be necessary for some applications, such as tremors, but we need to link it to the active research agenda.

- *Why do we want to understand a system at multiple levels?* A realistic model of **neuronal computation** is much more complicated than just a single-level contribution. As also explained in the background document on the dimensions of Neurotechnology, mind, brain, and behavior must be viewed as multi-scale dynamical phenomena.

- It is generally agreed that **hands-on training** is more effective and relevant than pure theoretical (factual) training and should be included in the NeurotechEU agenda.

- The educational programs do not have to be identical for every student; we must find ways to individualize the learning experience. Additionally, a possibility is to make multidisciplinary teams of students who engage with project-oriented tasks.

- In the dimensions of neurometaphysics and neurotechnology, there should be a **link to innovation and reach out to society** to open possibilities for the translation of science and technology to society.

Recurring questions to think about:
What are the basic questions, theoretical questions, that we should address in neuroscience and neurotechnology?
How do we train people, and for what goal?
How can we make sure to speak each other's language, or how do we develop a common one?
How do you work together if there are different questions and methods per discipline?
Do the fundamentals in neuroscience align between a researcher and a student?

Dimension 5 – Neuroinformatics

Present: Timo van Kerkoerle, Peter Szucs, Christian Henneberger, Sandra Blaess, Sandra Jurado, Laura Frutos, Maria José Such, Juana Gallar, Javier Castro, Can Yücesoy, Inmaculada Blaya, Necati Aras, Mathew Abrams, Oana Vanta, Cristina Iuga, Livia Popa, Minh Tue Ngo, Hector López Carral, Francisco Pascoa dos Santos, Vivek Sharma
Moderator: Paul Verschure
Rapporteur: Pam Graave

Neuroinformatics

To give an idea of the potential of neuroinformatics, Vivek Sharma of Radboud University (Ph.D. student of Paul Verschure's group) showed a virtual tour of BrainX3. BrainX3 allows integrated access to multi-modal structural and functional brain data accessible through interactive 3D models, their analysis, simulation, and their semantic annotation.

INCF (https://www.incf.org) is the international neuroinformatics coordinating facility founded in 2006 based on the work of the OECD Global Science Forum which started in 1995. INCF mainly focuses on data access, training, and computational neuroscience founded in 2006 based on work in the OECD Global Science Forum which started in 1995. It is primarily used by the neuroimaging and computational neuroscience community, mainly in North America. The current educational focus in different universities are on data management skills and developing necessary tools.

The Human Brain Project (HBP) and its successor EBRAINS has large-scale data sets, atlases, and models (e.g., through the virtual brain), and they have links to publicly available datasets through KnowledgeSpace. Such publicly available datasets may be interesting for NeurotechEU for education. Another area NeurotechEU needs to focus on in neuroinformatics is training on understanding best practices in neuroscience data. In neuroscience, we are obliged to make data available, but in practice, this still does not happen. Moreover, the wish to make data accessible is facing regulatory boundaries such as GDPR, which must be overcome. For this, curated datasets must be made available to support training.

Toolbox neuroinformatics

The current training practice in neuroinformatics methods in INCF is based on the medical teaching concept of See One, Do One, Teach One[3], and is realized mainly by postdocs and researchers working with undergraduate and graduate students. *What will the students be trained in, and do we need to make the toolbox for neuroinformatics education more specific?* Most universities have a computer science department with units in bio- and neuroinformatics, so tool development as such is not our main challenge. However, participants mentioned some ideas for the toolbox:

- **EBRAINS platforms:** The structure of EBRAINS is solid but still in development;
- **BrainX3:** BrainX3 is a handy tool for data integration and visualization and, thus education;
- **Python:** a useful programming language for neuroscience and is open source. Python is also easier for developers to integrate and a de facto standard in the field.

[3] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4785880/

Tools and infrastructure portfolio used in INCF

- **Training Space:** an online hub that makes multimedia educational content from courses, lectures, and exercises more accessible to the global neuroscience community[4].
- **Knowledge Space:** a joint development between the HBP, INCF, and the Neuroscience Information Framework that aims to create a globally used, data-driven encyclopedia and search engine for the neuroscience community[5].
- **Neurobot:** a clinical study data management tool that aims to easily search and find the study variables with the associated information[6].
- **Neurostars:** a Q&A forum that serves as a platform for knowledge exchange between neuroscience researchers at all levels of expertise[7].

Concerning skills and pedagogical methods, the suggestions raised were:

- **Being capable of talking to other disciplines:** Give people the capacity to understand what is happening around them. *Is the emphasis on training students to be consumers or also inventing new analysis methods?*
- **Reinvent the wheel**: leading the students to develop the method themselves. The idea is to give training exercises to reinvent the wheel.
- **Neuromatch academy's** approach is also to reinvent the wheel because the student has to do it alone. Their approach is very accessible and very well-documented, and they give students space and interaction. Students watch pre-recorded 15-minute lectures, but tutors discuss the student's opinions of the lecture afterward. On the other hand, Neuromatch academy is considered imperfect; big tech companies are behind it (which excites students), so we should be mindful of this.

<u>Ideas</u>

- We must distinguish what kind of setting we are talking about. *Is it a basic research or applied setting regarding the efficiency of the user and their possibilities in the clinic?*
- As a model, NeurotechEU can look at LearnGala [note: contact has already been established between NeurotechEU and LearnGala at Michigan State] and Neuromatch academy. *How can we incorporate this material into NeurotechEU? In what areas can NeurotechEU contribute to neuroinformatics*, and where are we redundant? It seems doable to capitalize on the tools, platforms, and experience of Neuromatch academy. It is open source, so we can publish it and link it to the archive videos.
- We should make sure to have translations into many languages in NeurotechEU so we can achieve a worldwide outreach.
- Training people to develop their hardware and software has also been brought up. Is that a team science effort or a singular expertise effort? Hands-on project-oriented training is an effective way to immerse people in a problem space and appreciate its complexity while developing problem-solving skills;
- Training students in advanced signal processing would also be beneficial, as we need this for different interventions and applications. Maybe we can build modules like that

[4] https://training.incf.org/

[5] https://knowledge-space.org/

[6] https://www.incf.org/resources/tools/neurobot

[7] https://www.incf.org/resources/tools/neurostars

within the NeurotechEU community by following and improving these modules that Neuromatch has already pioneered.

Tasks

We need to create these task forces for the coming period to give more context to the dimension of neurotechnology.

- **Task Force 1**: *What is the minimum neuroscience base for neurotechnologists? Where should the emphasis be on training modules?*
- **Task Force 2:** *What should be present in the neuroinformatics toolbox?*: What is the minimum toolbox training required for neurotechnology? How do we build the catalog for that? What platform does NeurotechEU want to use, and what pedagogical approaches? We should identify these gaps in knowledge that we can fill with the platforms we use, such as Gala, and take inspiration from Neuromatch. We can include INCF and EBRAINS for discussion on this matter.
- **Task Force 3:** *Deployment and user testing*. Plan a rolling set of workshops that help us to advance these training modules and to test them. Specifically, building a sort of Neuromatch repository and putting effort into the pieces that are not there yet.
- **Task Force 4:** *How to reach out to the network of experts?* Make a catalogue of the expertise available in the consortium and identify the expertise that needs to be further brought in.

NeurotechEU summit: Elaborating the NeurotechEU Content Space

Tuesday, September 13, 2022

Dimension 3 & 4 – Neuromorphic computing & neuromorphic control

Present: Timo van Kerkoerle, Peter Szucs, Christian Henneberger, Sandra Blaess, Sandra Jurado, Laura Frutos, Maria José Such, Juana Gallar, Javier Castro, Can Yücesoy, Inmaculada Blaya, Necati Aras, Mathew Abrams, Oana Vanta, Cristina Iuga, Livia Popa, Minh Tue Ngo, John van Opstal, Matthew Self, Melika Payvand (online), Chiara Bartolozzi (online)
Moderator: Paul Verschure
Rapporteur: Pam Graave

Neuroprosthetics

There are currently many challenges in neuroprosthetics, ranging from simply not having a good enough understanding of how the brain works to understanding how electrodes interfere with neuronal tissue. The main challenge is getting people with a broad enough education in neuroscience, computation, and engineering. Leading issues in the future regarding neuroprosthetics:

- The number of animal experiments and subsequent scaling up work to achieve translation of findings into the clinic will increase. Such translation is very slow, complex, and frustrating process that includes aspects beyond science and technology: *What are the best ways to recruit patients to become participants, to get ethics protocols approved and a to design solid clinical study protocols?*
- It is crucial to have expert knowledge in different fields to be helpful to some patients while such interdisciplinary knowledge integration has its own challenges. *How will we overcome major challenges of making durable prosthetics that can be chronically implanted and used and are specific for a range of neuropathologies?*
- Microstimulation depends on a broad set of anatomical, physiological and functional parameters, which requires a comprehensive understanding of underlying scientific and technical issues. For instance, *how can computational models assist in model identification and parameter estimation? How do non-human primate or rodent experiments inform decisions on what can be usable in humans? Also, what is the role of theory here in advancing neuroprosthetics?* This requires a constant back and forward addressing and feedback of concepts between basic and clinical research, technology and theory. It is crucial to sketch that landscape.

Neuromorphic computing

To introduce the challenges related to neuromorphic computing, a good place to start is NeurotechAI (https://neurotechai.eu). NeurotechAI aims to promote interaction with the stakeholders, advance roadmaps, and shape future development. Their vision is to realize more sustainable technology by learning from the brain and developing alternative paradigms such as low-power stochastic computing. In terms of strategy, NeurotechAI is moving away from traditional computing and advancing the neuromorphic engineering agenda initiated in the 1980ies by Carver Mead at Caltech.

- A neuromorphic engineer should understand how to exploit all the skills. The big challenge of the field is trying to understand how neural computation works and to emulate that in artificial systems. NeurotechAI suggests that analog computing seems necessary, e-memory computing is essential, and local computing is a new standard. This requires engineers that can understand neuroscience and computation and perform the translation to new hardware substrates. If NeurotechEU wants to focus more on technology, NeurotechAI will move forward so that the person in the middle has to be an engineer interested in biology. Yet, such a new interdisciplinary field brings even more challenges; for example, students and their mentors will not be experts in all related areas and face the problem of tackling an unknown number of unknowns.

- The necessary background of the NeurotechEU student depends on the objective. However, for a systematic approach, it is more effective for the student to have an engineering background and subsequently specialize in neuroscience. If the objective is to develop algorithms, it may be more favourable to be from a computing science background. If the aim is to develop more bio-inspiration algorithms, it is better to come from computational biology.

<u>**Neuromorphic computing and neurorobotics some conclusions:**</u>
NeurotechEU bares both the opportunity and challenge of training students on multiple very different topics. We must, therefore, develop a common language so that different disciplines can understand each other and collaborate. We can have workshops and start discussing with experts from other fields more structurally from an educational point of view in order to identify what common protocols can be.

- We need to ask ourselves if we want to have a fixed program or not; it could be **project-based**. Neurotechnology has multiple dimensions; every training trajectory will pass through multiple dimensions. This allows the creation of unique profiles for master training trajectories and individual career development. However, having an entire curriculum career built on a project-like, pick-what-you-want basis may reduce the structure in education. Primarily for engineering, one requires a structured teaching environment, instructing the basics of physics and mathematics necessary to apply to biological systems and their associated technologies.

- The opportunity NeurotechEU has is to contribute to the development of **interdisciplinary training**. A multi-disciplinary team of supervisors for Ph.D. students are indicated who can shape the career development plans and determine what the required knowledge and skills are.

- Finding someone with a background in neuromorphic engineering is almost impossible at the Ph.D. level. Therefor, the strategy can be to **train engineers** to specialize in biology, and not the other way around. To optimize the education trajectory, some topics could be de-emphasized. For instance, quantum mechanics could be provided as an elective in the regular undergraduate curriculum, creating room for introductory neuroscience courses. The discrepancy we have to bridge is that we do not know much about the brain regarding underlying principles. Yet, we know a lot about technology which is seeking continuous innovation. We need engineers in neuroscience to achieve this goal.

- We must be careful not to remove the imaginative perspective on science from the curriculum. If you start to shape people in the engineering and physics domain, they might **lose affinity with the big ideas** because they grow up in well defined, hence constrained environments. We should have beta-oriented training and a **psychological component** that challenges people to be able to articulate the bigger questions that will propel us into the future of science and technology.

- An inspirational example for NeurotechEU could be the paradigm of AMSL: we don't need a one size fits all education, but we need people who are highly skilled in specific domains which are brought together and create environments where the trained experts thrive through their collaborations.

- We should always make it clear to the learner why a particular essential skill is helpful in accomplishing a specific goal. Hence, it is key first to motivate people toward that goal. Once such goal with a rationale is defined, there is a logic for why certain basics need to be known. This can be further grounded in experience through project-oriented education.

General concerns raised

What are the boundaries of Neurotechnology and its curricula? For instance, if we include material science in the training program, we may say it is getting too broad at some point, yet a dictum of neuromorphic computing is to "listen to the silicon". *How do we balance these potentially opposing forces of breath and depth? Should we consider training a variety of profiles that mix these two opposing aspects of education? Should we think about neurotechnology as a subdiscipline that exists in parallel to other disciplines and acts as a focal point? Or do we alternatively reason from a common core from which we ramify into different specializations?* The consensus is that we should reach for such a common core, as the parallel lines already exist in education while integration is needed. Such a commitment would fuel the need to develop a common language. Given the structure of multiple dimensions along which educational trajectories are formed, the question is how much self-organization could be tolerated without compromising the ability to reach teaching outcomes. This creates the dilemma of normative and standardized programs versus open and student-driven learning trajectories. The NeurotechEU multi-dimensional content space can be seen as an umbrella that could provide sufficient constraints for student-driven curriculum development to be effective. This is especially true when combined with standardized workbenches and project-oriented challenges.

- *Is the dimension a profile, or is the educational profile a mixture of dimensions? How do we keep the learning motivated to address the big questions? How do we retain mental flexibility and creativity without losing the pragmatic capability to get things* *done?* We could accomplish this cognitive flexibility through team science training. We can realize neurotechnology as a team science if we have a common language.

- If courses are not compulsory, the question is how learners can make informed choices on topics they do not know. At these decision points, learning trajectories can be shaped through project and challenge-oriented training. This method will provide implicit guidance and create potential paths that learners can follow, driven by their interests and skills.

The pragmatics-big idea dilemma should be explicitly identified and addressed. Hands-on training situates learners in the problem space and grounds their knowledge and skills, while the big ideas give them a view of the future and a context for their specific activities and ambitions.

Dimension 6 & 7 – Neuroprosthetics & Clinical Neurotechnology

Present: Peter Szucs, Christian Henneberger, Sandra Blaess, Sandra Jurado, Laura Frutos, Maria José Such, Juana Gallar, Javier Castro, Can Yücesoy, Inmaculada Blaya, Necati Aras, Mathew Abrams, Oana Vanta, Cristina Iuga, Livia Popa, Minh Tue Ngo, John van Opstal, Koen Haak, Utku Yavuz, Jeroen Goossens, Lennart Verhagen
Moderator: Paul Verschure
Rapporteur: Pam Graave

Impact

To start the discussion about neuroprosthetics and clinical neurotechnology, we need to figure out how we would integrate technology into clinical practice and what neurotechnology challenges come with it. *What could be a paradigmatic model that captures these kinds of neurotechnology and neuroprosthetics, is there a standard model?* And, importantly, *what competencies do we need to make this dimension work?*

The usual path of fundamental science is to generate some results and afterwards think about how they might be helpful. We might need to reverse this direction and start thinking about the **impact** (such as clinical and economical) and then later derive what we need to achieve it. If we want to align education with targeted impact, more needs to happen than just reordering things into different groups of disciplines, in order to avoid actions restricted exclusively by paradigmatic habits. *When is impact sufficiently relevant? How much priority should impact have in research and educational programs? And how broadly should that impact be defined: non-scientific terms, economic impact, psychological cost?* Some big problems may be worth pursuing, despite the lack of all relevant knowledge, because such a significant impact is to be achieved. This can be defined as the impact on society as defined through disability-adjusted life years (DALY). Targeted challenges include, e.g., addiction, anxiety, depression, dementia, stroke, etc.

As scientists, we can be more selfish and state that neurotechnology will help us understand the brain. Yet conversely, the question and hypotheses must be defined sufficiently clearly to provide specifications for new technologies to be developed, i.e., avoiding the technology in search of a problem trap. Eventually, science can meet needs that have not yet been known instead of having an immediate impact, such as curing diseases.

Challenges & opportunities

- We have already identified some challenges and bottlenecks that we currently experience, such as an **interdisciplinary knowledge exchange**. Finding students and researchers who can build bridges between and across disciplines and accomplish successful outcomes of projects that desperately demand such interdisciplinarity is challenging. What do you need to make these projects a success? However, this requires ideas, drive, and resources and, thus, the involvement of various stakeholders.
- One trajectory towards innovations originates in clinical trials rather than new developments in animal models or a better and more fundamental understanding of neuroscience. This trajectory can lead to serendipitous discoveries. In this case, however, Louis Pascal's dictum holds that divine providence favors the prepared mind,

and thus the objective of educational programs aims to prepare future researchers' minds. In the philosophy of science, this is also addressed as the logic of discovery versus that of verification.

- Conversely, the concept that NeurotechEU follows is that development and training in technology require grounding in fundamental principles, i.e., the neurotheory dimension.
- NeurotechEU needs a cross-dimensional, cross-scale, open-source training program with a common goal pursued through team science. Here we can learn from other disciplines. For example, CERN works in a way where no one knows entirely how the whole machine works, but they have a team that makes it work. *Do we have that in neuroscience?* We should define common goals and create teams that work together on these goals. Yet, we also must recognize that the significant difference between the disciplines is that CERN's activities are orchestrated from a common theoretical perspective that still has to be developed in the life sciences and also neuroscience. A novelty here is that, as articulated in the document on the eight dimensions of Neurotechnology, it is the creation of technology that can facilitate in developing that theoretical framework.

- **American funders** would like to see only a handful of disorders in application fields of neuromodulation rather than everybody going forward over a broad front. It would be helpful to clearly focus on where to get the training project started. Yet, NeurotechEU is a European project that helps it forge its own path, and here we should be guided on the disease burden on society, e.g., via the earlier mentioned DALY tables.

- A crucial question is how we can train highly specialized engineers who care to have an **intuition about the broader challenges society is facing**. In training programs, we could give them intellectual tools and skills to let them see the opportunities that align with these societal challenges. It could be like obtaining a medical degree, not just by studying anatomy and clinical interventions but also by patient care and wellbeing, i.e., reaching towards the non-physical aspects of health and thus a multi-scale perspective. In education, we must think about the context of neurotechnology and educate that as well instead of just the neuro or engineering part in isolation. The goal is to make students appreciate the multi-scale organization of mind, brain, and behavior and to think and realize what and where they want to have an impact and can achieve that goal.

- CERN is an example of how something big can happen. *Should this* ***moonshot focus*** *be the goal of NTEU? Should it fall entirely into a singular research focus?* We have a multiscale challenge, unlike CERN. Everyone has to have, to some extent, an understanding of these different domains. *How do we do that without losing specific skills?* For medical education, one starts with a broad program to shape a common language; from there on comes specialization. It is something to consider. Similarly, CERN is something to consider. Yet, we should not ignore the fundamental differences between these domains and the limited impact medicine has had on most neuropathologies. Therefore, students must be trained to be able to see the boundaries of their field and feel encouraged and able to cross these.

- NeurotechEU will be seen differently depending on the level of the student, for a bachelor student or someone with a postgraduate degree. Also, each will be engaged in Neurotechnology from different contexts, e.g., a medical student's background will be different from an engineer's. As a result, there will be **different sets of knowledge and skills** we must convey to them while **facilitating convergence** through the development of a common language.
- Typical multiscale challenges we expect Neurotechnologists to address in the medical domain are the challenges of diagnostics and prognostics. A measure of the brain used as a diagnostic biomarker can have some quantitative predictive power, yet it might be challenging to translate to the patient what is meant by this form of diagnostics. Here, **neurotheory** and **computational theory** come into play. Computational models may be essential to improve the quality of care or the quality of prognostic power in the clinical decision-making pipeline, which is an emerging trend. Yet, this calls for interpretable computational tools.

- Developing a **common language** could be part of the goals of NeurotechEU, as well as understanding and training people in that common language. *What could be forms of such a common language?* From the perspective of someone technically trained, computational models can be central to such a common language. From a clinician's perspective, however, this may be difficult to translate or interpret, creating a training objective.

- *Why not use goals or missions as a common language?* One suggestion is to use computational models as a common language, also in neuroscience and neurophysiology. Individual technologies cannot be considered a common language because they are transient and, at best, an implementation of a description of reality. *So, what is the most sustainable language which can serve Neurotechnology in the long-term: concepts, methods or computational, or a combination thereof?* An alternative perspective is to *seek common languages at different levels, i.e., level of description-specific languages with protocols for cross-linking.*

- *The development of a common language is one of the challenges of neurotechnology*. We could advance on this challenge through small pilot projects. Small enough teams make it easier to arrive at models of a common language. Maybe we could prioritize missions with a kind of dynamic that can constructively contribute to advancing this challenge. Yet, the NeurotechEU contribution is to train future researchers to contribute to addressing this challenge of a multi-scale understanding of mind, brain, and behavior and be able to develop brain-compatible technologies. This implies to train for an appreciation of the tower of Babel we are currently inhabiting.

- Neurotechnology seeks to impact health through innovation and constructive disruption. However, the current structures in which we provide healthcare are a significant obstacle in the case of scaling and employing neurotechnologies to have an impact. The only way to navigate the rigidity of institutional structures is a solid understanding of how the medical health care system works. A path into the future is also to train future researchers to disrupt existing structures and thus instill innovation and progress. NeurotechEU can revolutionize care pathways when it creates a new spirit of medical research. We must train next-generation researchers to be able to stray from the common path and understand that they can work within and outside the status quo of the current system.

- NeurotechEU trajectories should include **innovation capability**: have big ideas and be confident enough to realize and bring those out. The route forward should not only be to talk to industry but also to build self-confidence and entrepreneurship in the next generation of researchers without boundaries. This innovation capability being a part of the research agenda should also be a part of such novel education agenda.

Dimension 8 – Neurometaphysics

Present: Timo van Kerkoerle, Peter Szucs, Christian Henneberger, Sandra Blaess, Sandra Jurado, Laura Frutos, Maria José Such, Juana Gallar, Javier Castro, Can Yücesoy, Inmaculada Blaya, Necati Aras, Mathew Abrams, Oana Vanta, Cristina Iuga, Livia Popa, Minh Tue Ngo, Hector López Carral, John van Opstal, Tony Prescott, Erik Vinkhuyzen (online), Anna Mura, Jan Branssen
Moderator: Paul Verschure
Rapporteur: Pam Graave

Introduction
Jan Bransen from Radboud University described several contexts in which scientists work (defined by Philip Kitcher, philosopher of science). Universities have focused on just one of those four in which the scientists work: the context in which they are busy trying to answer questions they somehow take for granted. Most scientists working in labs are directed toward specific questions because they prepare to give certain answers. If a scientist works in a lab and is thus connected to that lab, this creates the impression that particular questions are more relevant than others because it is those questions the scientists can handle. The second context concerns how scientists will create inquiry opportunities once they have those questions and are exposed to finding ways to answer them. However, the scientists may need to solve issues that might require a contrary approach. Additionally, scientists tend to neglect new approaches when educating the students and just bring in their own practice. Last is the context of application, which suggests the acceptance of a knowledge-action gap. However, the idea that scientists solely produce knowledge and hand that over to others could be the wrong model for building science. Philip Kitcher is aware of the fact that doing science, requires doing democracy. Doing democracy may be an essential part of science, but this is not taught to students.

It would be most productive to mix applied and basic science and find the sweet spot where both can be done. People will come to NeurotechEU because they are looking for careers and a life in science that is meaningful for society. It is about linking this form of science and personal ambition that will matter and be relevant.

How much freedom is there still in terms of what you (are allowed to) learn? If knowledge and learning are driven by industry, academia is a service provider to industry, applying something in society to serve the industry. Here science and academia can represent the needs of society and work towards these through a mission-oriented approach.

NeurotechEU should provide a model for the learning space, deconstructing the learning structure as we know it and opening new spaces to perform, explore and act towards basic challenges.

The needs of society influence and shape science and result in constraints to provide a successful product. These needs are the driving force in European programs nowadays. Still, we have the opportunity to rethink and discuss them by considering, for instance, by considering multiple time scales at which challenges emerge.

Neurometaphysics

- The role of neurometaphysics can be to establish an interface between science and technology with culture and society. We must train people in engineering/sciences and in philosophical contexts to make both of these domains operational. Yet, senior PIs themselves are not educated this way, which needs to be changed and NuerotechEU can bring such change about.

- Community of learning/practice, how to avoid an "us and them" culture in science and technology and this fragmentation and unnecessary contrast? There is a difference between a community of practice, where one knows what the practice is, and a community of academics who should excel in being skeptical and celebrating their ignorance. We need to create a community where one feeds openness and curiosity also by considering the practice of science and technology.

- Teaching the **philosophy of science** in a neurotechnology program would be radical and relevant. The philosophy of science says that explanations are not testable; they can generate a hypothesis, but if it is falsified, you find another explanation in a continuous cycle of paradigm construction. Future researchers must have a scientific meta-cognition that allows them to recognize these patterns.

- To sharpen theories, we should train our next generation of researchers through interactions and loops between basic science and application. Besides, we should sensitize each other and the next generation to the fundamental challenges we face, the big questions which give direction and define missions. We should prepare young people for facing the unknown and constructively reshape it into the known.

- **Task:** We have to follow up on this discussion**.** We are implicitly defining an educational approach to neurometaphysics and neurotechnology, and this deserves further analysis and debate.

Neuroethics

Many research projects touch upon ethical boundaries. Yet, the ethics considered in many current research projects are pro forma; a box must be ticked. *How do we place ethics more at the heart of science and technology and thus impose its effects on the training of the next generation?*

- We have to consider the issue of micro-ethics; this has to do with, for instance, **psychological safety** in the educational setting.

- An essential aspect is to provide training on how to deal with the interpretation of our data and how to communicate it. It is crucial to consider to what extent the collected data helps address questions rather than collect the data because it is technically possible. *What ethical limitations does research have, and what hurdles do research techniques face?*

- There are two main views regarding technology. There is a dystopian mainstream humanist view against the use of AI originating in the philosophy of Adorno. The other utopian view is a post-human one, which would say that the human condition constantly changes, and that new technology contributes to this process. We must realize that the debates between these views will continue; thus, NeurotechEU should train students to be informed participants in this debate.

- One new approach is to include **experimental neuroethics** in neurotechnology to make fundamental ethical challenges addressable again through scientific methods and technology. For instance, where we investigate questions such as what pain means and whether an artificial system can experience it.

- NeurotechEU must develop a clear view of what it delivers to society: scientists, technologists, clinicians, or all three. Nowadays, there may be too much knowledge produced, and we have to distinguish between what is validated knowledge and what is noise. Here, the learning objective could include the ability to constructively engage with the deluge of papers and data, avoiding being robotized in practice, which will be a growing future problem. In this respect, one possible mission is not to accelerate too much and instill a sense of slow and deliberate practice. The dependency on the context in which Neurotechnology exists might not be conducive to such a paradigm shift.

- Creativity must be free of coercion and can only flourish in freedom and, thus, democratic structures. We need the brain's creativity to find solutions to current and future challenges. Freedom of thought is involved in providing the best solutions.

- We need to make a toolkit to help the student manage all challenges around Neuroethics.

<u>Scope of neurometaphysics</u>

- Is NeurotechEU built on the perspective of teaching or of the student? The opportunity is to create programs that don't exist today and assist in solving fundamental challenges. This also requires that teachers grow and be responsive to change and receive the proper support and training.

- There was some discussion about the label of 'neurometaphysics'; why not something such as neurophilosophy? However, we do want to avoid creating conceptual conflicts, and for this reason, the notion of 'neurometaphysics' is novel and constructive.

- **Neuroexistentialism should be considered.** We should talk about the contribution of brain science and neurotechnology to the meaning and purpose of life.

- **Lifelong learning challenge** is a significant trend worldwide, and in NeurotechEU, we should also develop this opportunity, the plan also includes efforts in this direction that need further development.

- **Neuropedagogy** is one of the prime application areas of neurotechnology, i.e., to learn is to change the brain. Thus far, many pedagogical methods are not sufficiently grounded in neuroscience and neurotechnology, creating opportunities for the field.

- *What should be the focus?* We should consider the vision and expectations of the student and be careful of the biases created by past approaches towards education. The challenge is to build a program that is grounded in the flourishing of the students rather than that of the expert; i.e., we should not assume that a domain expert is automatically an expert in pedagogy.

- *Where should NeurotechEU incorporate decision neuroscience?* The dimensions of neurotheory and neurorobotics capture decision neuroscience. We are building from neuroscience through **neurotheory**, and not specifically within neuroscience.

- NeurotechEU is based on eight dimensions of neurotechnology, and every learning trajectory of a person will be defined along those dimensions. Training modules at different levels will fill out every dimension, and students can choose their trajectory as an individual, thus facilitating the individualization of their training. A concern is that learners are not necessarily aware of their proximal learning zone, using the constructivist terminology Vygotsky. Therefore, the NeurotechEU program needs to think about its user model of the learner and, for instance, give them enough confidence and safety to enter that proximal zone.

- Student concerns consist of which level of organization NeurotechEU talks about, as the student cannot excel in every discipline. Knowing about the student's background is essential to consider the programs NeurotechEU is developing. Besides being careful about what hands-on practice means in terms of the eight dimensions of Neurotechnology, we need to accommodate the various backgrounds of the learners.
- Representatives from the student council are encouraged to give their suggestions for NeurotechEU curriculum development and pedagogical methods and share their views on how they would like to move forward. Also, students do not have to be an expert on everything; the idea is to learn to explore knowledge spaces and ground-acquired insights in concrete skills.