



Utrecht University

Freudenthal Institute



Scientific and Mathematical Literacy in Life and Society

Research program Freudenthal Institute 2021-2026

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Management Summary

The Freudenthal Institute is a multidisciplinary institute concerned with science and mathematics education, science communication, and the history and philosophy of science. It contributes to resolving societal issues through fostering the scientific and mathematical literacy of students, citizens and professionals. As such, the Institute's mission is to advance the "why, what, and how" of formal and informal science and mathematics education.

To fulfill this mission, the Institute's research aim is to understand and to foster effective education for scientific and mathematical literacy, based on knowledge from the educational sciences, science communication, and the history and philosophy of science. Scientific and mathematical literacy is defined as the ability to engage with science and mathematics related issues and with the ideas of science and mathematics as a responsible and reflective

citizen. The Institute plays a central role in research-based innovations in the Faculty's teaching, and in outreach and valorization activities in educational practice and society.

The Institute's research program 2021-2026 focuses on four research themes.

1. Science in society
This theme concerns the position of science in society today and historically. How has scientific knowledge been developed and perceived in society over time, how do communication and mutual engagement between science and society take place, and what knowledge of and about science do citizens need to deal with socio-scientific issues?
2. Scientific and mathematical literacy education
This theme concerns how to foster scientific literacy in science and mathematics education through innovative approaches, ranging from the micro-didactic content



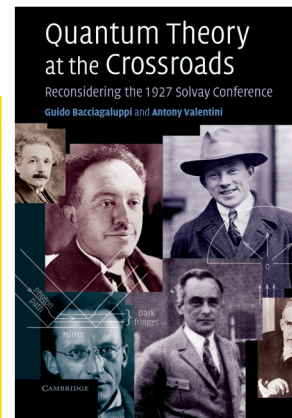
Inclusion and Diversity through Science Communication

Inclusion and Diversity is an important theme in FI's science communication research projects and related MSc theses. Research shows that Dutch science museums recognize inclusive education as an important aim, but experience difficulties in obtaining an inclusive staff. They still characterize their dominant visitor as highly educated, white and having a relatively high income. As another example, a literature study has been carried out on "Reducing gender bias in popular science texts". This has inspired the course 'Trends in Science Communication' in which students apply an analytical framework on gender bias to popular science texts and rewrite them to reach a more diverse public.

Quantum Theory at the Crossroads

Scientific development is far more dialogical than one might think, and both consensus and conflict are crucial components of scientific practice. This is perfectly illustrated by the development of quantum mechanics and the interpretational debates that accompanied it.

Perhaps the most important meeting in the history of quantum theory was organized by Solvay in 1927. Contrary to popular belief, the interpretation of quantum theory was not settled at this conference, and no consensus was reached. Instead, a range of sharply conflicting views was presented and extensively discussed, including de Broglie's pilot-wave theory, Born and Heisenberg's quantum mechanics, and Schrödinger's wave mechanics (Bacciagaluppi & Valentini, 2009).



level to the macro curriculum level. How do we achieve higher order educational goals, foster student motivation for and engagement with science, and realize equity and inclusion in education?

3. Digital technology for scientific literacy
This theme concerns the ways that digital technology can be used to foster scientific literacy. Digital technology includes digital humanities, augmented, mixed and virtual reality, and virtual classrooms (as implemented in the Teaching & Learning Lab). How can these tools be used in secondary and tertiary education, teacher education and applied data science?
4. Scientific literacy in tertiary education and teacher education
This theme concerns the question of how to foster scientific literacy in tertiary education, including that to the pre-service teacher and the future scientist. It focuses on the mutual relationship between research and tertiary teaching. How to support tertiary teachers' professional development? What encompasses academic research integrity, and how do we educate future scientists in this respect?

To investigate these themes, FI integrates and further develops different research methods, including design research, lesson study, and methods to study digital historical databases. Methodological boundaries between

the different disciplines will be crossed, leading to innovative research approaches. Special attention is paid to research quality with respect to ethics, integrity, and privacy, both in the Institute's research work, and in the education of PhD students at Utrecht University.

In realizing the research aims, also in the coming years, the Institute collaborates closely with partners within the Faculty of Science and University University as a whole (e.g., the Centre for Academic Teaching, Educate-it, and the Descartes Centre), with partners at the national level (e.g., KNMI, RIVM, VSNU, SLO, science museums, and the educational field through the U-Talent network), and at the international level. These collaborations at different levels provide ample opportunities for external funding.

To successfully implement the research program, several actions will be undertaken. The research agenda will optimize synergy through multi-disciplinary teams that apply for grants and carry out research projects. The research base on science communication will be improved through collaboration and attracting new staff members. Research quality will be monitored through fine-tuned procedures for quality checks, and open science standards will be respected. The Institute's societal relevance, viability, and academic culture—though highly valued in assessment reports— will be further enhanced.

Scientific and Mathematical Literacy in Life and Society

Research program Freudenthal Institute 2021-2026

Introduction

The Freudenthal Institute (FI) is a multidisciplinary institute concerned with science and mathematics education, science communication, and the history and philosophy of science. It is home to researchers, teachers, and other experts on the boundary between science and society. This versatility generates scientific and practical knowledge, rooted in the scientific disciplines—physics, chemistry, biology, computer science, and mathematics—as well as in educational science. These contributions impact on teaching practices within Utrecht University's Faculty of Science, in which FI has a unique position (e.g., through the Institute's Teaching & Learning Lab). In addition, the Institute has national and international outreach, for example through the U-Talent program and European research projects. FI is the ideal partner in addressing contemporary societal and educational issues in the field of science and mathematics that require science-based solutions.

After the merger of the Freudenthal Institute for Science and Mathematics Education and the Institute for History and Philosophy of Science in 2014, the new Freudenthal Institute established its research program for the period 2015-2020. This program, entitled "Scientific and Mathematical Literacy for Life; Educating for Scientific Citizenship," proved to be successful, and received external research assessment qualifications ranging from very good to excellent.

Now the time has come to update the Institute's research program for several reasons. Societal demands with respect to science and education are in transition. The external research assessment has led to identifying new goals, VSNU's Standard Evaluation Protocol 2021-2027 highlights specific criteria for research quality and societal relevance, and the Utrecht University Strategic Plan 2021-2026 suggests new research directions, such as a focus on sustainability, lifelong learning and interdisciplinarity, as well as on the UN's Sustainable Development Goals (SDG). The Freudenthal Institute's work is clearly relevant to SDG 4, entitled "Quality



Sustainability as a Socio-scientific Issue

Today, sustainability is a societal issue. Climate change and energy transition, for example, are in the news daily. Environmental citizenship includes dealing with personal values, and societal and ethical aspects of science. As such, sustainability is a topic where society and science meet.

Science education aims to prepare students for responsible opinion-forming on these topics, which is challenging for science teachers. FI collaborates with a team of secondary science teachers to foster sustainability education. Following a Lesson Study approach, the team explores the opportunities of Socio-Scientific Inquiry-Based Learning to facilitate lesson design for environmental citizenship (Gericke et al., 2020; Knippels & van Harskamp, 2018).

Inclusive Science and Mathematics Education

In today's multicultural society we need to address inclusion in education. Teaching methods inspired by inquiry-based learning benefit from diversity in the classroom and have the potential to connect science, culture, and decision-making. Teaching materials that offer role models from various cultures, use multicultural contexts, and provide access to the non-western history of science and mathematics create opportunities to involve all students and to view cultural differences as a resource rather than an issue (Maass et al., 2019).



Which shapes do floor plans of places of worship have?

education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all”, and can contribute to other SDG’s as well.

The current document, therefore, outlines the Freudenthal Institute’s research program for 2021-2026, and positions the Institute’s research for the coming years within the above-mentioned frameworks. It elaborates on relevant themes from the previous program, which is reflected in the title and in a continuing focus on scientific and mathematical literacy. In addition, the program identifies new opportunities and challenges to be addressed and provides guidelines for the upcoming research activities, in accordance with the Strategic Plan 2021-2026 and the mission and core values of Utrecht University.

Research Aim

Empowering citizens and professionals

The natural sciences and mathematics play central roles in many of today’s societal issues, such as sustainability and the current covid-19 pandemic. The results of scientific research have a far-reaching impact on citizens’ private and professional lives worldwide; in the meantime, the

importance of science is sometimes contested, and “alternative facts” have entered the debate in the media. Therefore, it is important that citizens are familiar with science and contemporary developments within science to the extent that they can recognize “fake news,” that they can make informed decisions on societal issues, and can deal with the technology that is part of their lives. Furthermore, science and mathematics education are gateways to higher education and future careers. At present, many groups of citizens are underrepresented in science, and much is to be gained in terms of equity; an inclusive society should support all citizens to engage with powerful scientific and mathematical ideas.

The scientific knowledge that citizens need to deal with science in society is referred to as scientific and mathematical literacy. The acquisition of scientific and mathematical literacy is important to all citizens, including future engineers, nurses, and journalists, and to society as a whole. The Institute, therefore, contributes to societal issues through fostering the scientific and mathematical literacy of students, citizens, and professionals. As such, the Institute’s mission is to advance the “why, what, and how” of formal and informal science and mathematics education.

Scientific and Mathematical Literacy

Scientific and mathematical literacy is the ability to engage with ideas and issues related to science and mathematics as a responsible and reflective citizen. Scientific and mathematical literacy—or simply scientific literacy—includes knowledge of the nature of science and mathematics. An awareness of the historical and philosophical foundations of science and mathematics, and a sensibility to what science and mathematics are about and how they can help in dealing with issues in private and professional contexts are part of this literacy. Scientific literacy encompasses the ability

- to explain phenomena scientifically, evaluate scientific enquiry, interpret data and diagrams, and apply scientific knowledge in the context of real-life situations (OECD, 2017),
- and to reason mathematically and to formulate, employ and interpret mathematics to solve problems in a variety of real-world contexts (OECD, 2018).

Clearly, scientific literacy concerns the whole field of knowledge and skills that people need to deal with scientific aspects of their lives and jobs. It ranges from basic numeracy and the interpretation of visually depicted information to higher order thinking skills, and includes mathematical literacy, data literacy, statistical literacy, and digital literacy (Golumbic et al., 2020). It is this broad

interpretation of scientific literacy that guides FI's research program.

How scientific literacy can be promoted is an important question. Its acquisition is not limited to formal in-school education. It involves lifelong learning processes through, for example, out-of-school activities and science communication in the media.

Altogether, scientific literacy plays a threefold role in FI's research: as a learning objective in science and mathematics education, leading to research on how to foster its development in formal education, as a guiding principle in the design and evaluation of informal science education and science communication, and as a subject of study from the perspective of the history and philosophy of science. Establishing a further foundation of the concept of scientific literacy and its acquisition is one of the goals of the Institute's research for the coming years.

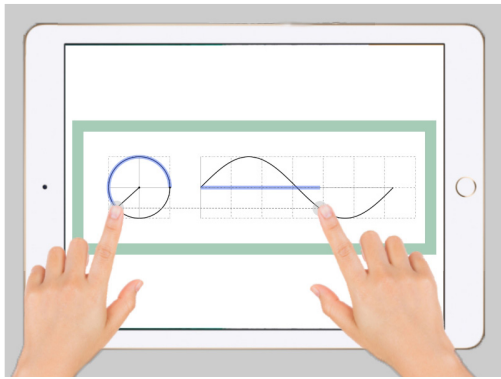
Rationale

In line with the Institute's mission, the central research aim is to understand and advance effective education for scientific literacy, based on knowledge from educational science, science communication, and the history and philosophy of science. Guiding questions concern the "why, what and how" of scientific literacy education: Why do



Sustainability in Chemistry Education

Chemistry as a discipline takes a central role in the current shift towards creating a sustainable society. The topical movement 'cradle-to-cradle' is an innovative and optimistic view on recycling, in which life cycle reasoning is a fundamental skill. We aim to engage pre-university students in cradle-to-cradle design problems that are rooted in organic and polymer chemistry, to provide and enrich their perspectives on chemistry in sustainability issues. We will deliver evidence-based guidelines for teaching sustainability and life cycle reasoning to students (de Waard et al., 2020).



The Digital Turn in Epistemology

It has been argued that knowledge is rooted in the interaction between the human body and its environment (embodied cognition), and that this interaction is increasingly mediated by digital technology (extended cognition). One important question for the philosophy of mathematics is what this implies for the nature of mathematical knowledge and how practical know-how can be modeled. Within mathematics education, insights into embodied and extended cognition raise questions about how learning can be supported by embodied interaction with specially designed tablet applications. One exemplary design stimulates students to relate the unit circle to the sine function (Alberto et al., 2019)

citizens, students and professionals need scientific literacy to meet societal challenges in their lives, education, and jobs? What type of scientific literacy is needed for that? How can it be fostered in formal and informal education and in science communication?

To address the why-question, we study the position of science in society from a historical and philosophical perspective. Under the label of Science in society, we investigate why science and scientific literacy, as they developed over centuries, have been important in empowering citizens to deal with socio-scientific issues. Communication and mutual engagement between science and society are included in this research theme, that connects to FI's master's program History and Philosophy of Science.

To address the what-question, we investigate opportunities to address scientific literacy in today's curricula. This includes issues of curriculum design ranging from a micro to a macro level. We design and evaluate innovative learning environments for science and mathematics; innovative both in the contemporary topics that are at stake, and in the teaching and communication methods. In this line of research, entitled *Scientific and mathematical literacy*

education, higher order educational goals are addressed, and equity and inclusion are guiding principles.

In addressing the question of how to educate for scientific literacy, the role of digital technology is an important topic today. How can digital technology foster formal and informal scientific literacy education? How to design and evaluate technology-rich learning environments is a third research theme called *Digital technology for scientific literacy*.

As part of Utrecht University's Faculty of Science, the Institute is particularly interested in *scientific literacy in tertiary education and teacher education*. How can faculty staff and students develop means to address the acquisition of scientific literacy? How to maintain research integrity? This theme is closely related to FI's master's program Science Education and Communication, in which future science and mathematics teachers are trained.

To summarize, we identified four research themes to address the Institute's mission and research aims for the coming years: Science in society, Scientific and mathematical literacy education, Digital technology for scientific literacy, and Scientific literacy in tertiary education and teacher education. These themes are elaborated in the next section.

Research Themes

In this section, the four research themes that form the Research Program, including the main research questions, are briefly elaborated.

Theme 1: Science in society

This research theme concerns the position of science in society today as well as in the past. It includes attention to how fundamental scientific knowledge has been developed historically (Bacciagaluppi & Valentini, 2009), how it has been perceived in society over time, how communication and mutual engagement between science and society take place, and what knowledge of and about science citizens need to deal with socio-scientific issues. The covid-19 pandemic provides a topical example of how these perspectives interact in critical situations. A historical example concerns the spread of leprosy in colonial Surinam (Menke et al., 2020).

In investigating the development of science in the past, we research the nature of science, in the eyes of both scientists and the public, and how it developed historically. It is important to know how scientific knowledge was appreciated in society over time, what its status was, and

how it impacted on private lives, professional activities, and political decisions (e.g., Theunissen, 2012). This topic connects to FI's master's program History and Philosophy of Science.

Science communication is a crucial factor in the relationship between science and society (van Dam et al., 2019).

Therefore, we investigate how scientists communicate with the public to facilitate citizens in taking an informed stance on socio-scientific issues, and to deal with "science denial." What fosters public engagement in and motivation for science, so that they contribute to scientific literacy? How do scientists combine reliable research with societal relevance? How to foster the development of robust science in dialogue between science and society? Which roles do media play in the perception of science in society? How can we utilize innovative audiovisual media and (ICT) tools to create and support science communication practices?

A next question concerns the knowledge of and about science that citizens need to critically consider scientific findings, and to analyze the complexity of socio-scientific issues to take an informed stance on how to deal with them, taking into account different values (Knippels & van Harskamp, 2018). It involves the ability to understand



The Teaching and Learning Lab

The Freudenthal Institute hosts the Teaching & Learning Lab (TLL), that consists of two flexible active learning spaces and a studio for knowledge clips and synchronous teaching. Since its start in 2016, the TLL has set the example for a range of active learning spaces across the campus. The lab collaborates with lecturers from all faculties, the Future Learning Spaces project, the Centre for Academic Teaching, Educate-it, and manufacturers of educational tools, and organizes an annual nationwide Autumn Festival on education and technology. Examples of research projects include lesson and classroom studies, using a camera set-up and embodied mathematics learning.

Research Integrity at Utrecht University

Pressure to publish is high, especially for young researchers. As a result, the risk of sloppy science and scientific misconduct increases. Therefore, young researchers need to be educated in responsible research practices. Such research integrity education should not only focus on evident violations such as fraud and misconduct. Views of good and responsible research practices in complex environments, such as interdisciplinary and international collaborations, and research with third party and/or public involvement should be included. In several international projects, FI investigates these matters. The findings will result in courses in scientific integrity for bachelor, master and PhD students at Utrecht University and in institutes of higher education throughout Europe.



scientific reasoning and the use of models to inform policies on contemporary issues, such as climate change, sustainability, genetic modification, health issues, privacy, and the role of technology in life. Also, we investigate which scientific literacy citizens need to assess the value of scientific research, to distinguish scientific insights from “fake news,” and to understand the role of scientific and mathematical models, including the inherent uncertainty in them. This topic connects to the next research theme.

Theme 2: Scientific and mathematical literacy education

This research theme concerns ways to foster scientific literacy in science and mathematics education ranging from a macro to a micro level and as such connects to the FI's master's program Science Education and Communication.

At the macro level, we design learning trajectories and curricula for science and mathematics education that offer ongoing learning tracks for overarching educational goals such as scientific reasoning and modeling (Jansen et al., 2019), macro-micro thinking (Bulte, Meijer, & Pilot, in press), system thinking (Gilissen et al., 2020), and higher order thinking skills such as mathematical and computational thinking (Drijvers, 2015; Pérez, 2018). Using insights from educational science and history and philosophy of science,

we investigate which higher order thinking skills and meta-cognitive skills should be included in science and mathematics curricula, and how they can be addressed.

At the micro level, we aim to design and evaluate innovative student activities and learning environments to foster scientific literacy. The innovation concerns the content: How to foster students' awareness of the nature of science? Which topics in science and mathematics education should be taught to foster students' future-proof scientific literacy and to prepare for future studies and careers—topics such as sustainability, climate change, and digital literacy, both in formal and non-formal education (Paraskeva-Hadjichambi et al., 2020)? How to assess these topics? How to highlight cross-cutting concepts and meta-cognitive skills related to science, such as systems thinking, modeling, and pattern recognition, perhaps in integrated STEM courses?

The innovation also concerns new forms of learning and teaching, such as inquiry-based learning (Verhoeff et al., 2017), open schooling, and realistic mathematics education (Van den Heuvel-Panhuizen, 2020), that may help students engage in science and mathematics and impact on their attitudes towards science and mathematics (Savelsbergh et al., 2016).

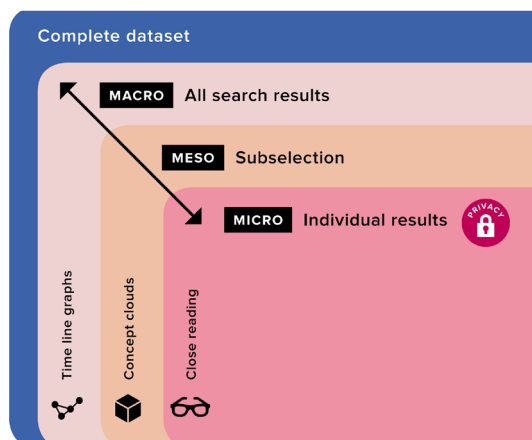
Theme 3: Digital technology for scientific literacy

This research theme concerns the ways in which digital technology can be used to foster the development of scientific literacy. In line with the Institute's past performance on designing, using, and evaluating digital tools and knowledge clips, this theme addresses the opportunities of recently developed digital technology for learning, teaching, and student engagement in formal and informal education. It includes developing frameworks to understand how and why digital technology may foster learning. This theme connects to the other research themes in different ways. In relation to theme 1, we investigate how applied data science and digital humanities may foster scientific literacy and an awareness of the historical development of science and mathematics in informal education.

Related to theme 2 is the focus on augmented, mixed and virtual reality to foster and assess scientific literacy (Cai et al., 2019). What new opportunities do improved user interfaces such as virtual and augmented reality devices, multitouch screen technology, handwriting recognition, and motion sensors offer for embodied approaches to

scientific literacy? Initial designs and studies in mathematics education (Drijvers, 2019; Shvarts et al., 2019), physics education (Pouw et al., 2016) and in teaching computational thinking (Francis & Davis, 2018; Manches et al., 2020) need further elaboration to find out how embodied approaches to learning in formal and informal education may foster scientific literacy.

Related to teaching, but also to the role of the teacher (theme 4), is the question of how the use of digital technology such as observation systems—like the one available in the Institute's Teaching and Learning Lab—may foster science and mathematics teacher training. How to shape blended and hybrid teaching, integrating face-to-face teaching and teaching at distance? How to use media for education at distance, e.g., the Virtual Classroom and lightboard video, to support interaction and learning at distance, and how to design blended teaching and learning sequences? How is teaching transformed through the integration of digital technology? Applied data science and advanced techniques such as learning analytics may foster these directions of research.



Media and Socio-scientific Issues

Today, large datasets with great social and historical relevance are available to researchers. Digitized archives of newspapers, radio, television, and other historical records, as well as online forums and social networking sites are expanding at a fast rate. These materials can be of vital value to historical research on socio-scientific issues (e.g., climate, drugs, and infectious diseases). How do mass media relate to public debates on socio-scientific issues? To answer this question, we use a specific digital research levelled approach in which we combine distant and close reading, which is common practice in digital humanities (van der Molen, van Gorp, & Pieters, 2019).

Collaboration with HU University of Applied Sciences

Sustainability issues deserve a more prominent place in secondary science education. Teaching about sustainability (or for sustainability) is rather different from regular science teaching: the system is complex, the field is interdisciplinary, there are many uncertainties, and emotions and moral issues are involved. The purpose of this study, therefore, is to conceptualize the Pedagogical Content Knowledge (PCK) science teachers need to address sustainability issues, and to find effective ways to develop such PCK in an interdisciplinary teacher education course. This design research project is situated within the Science and Geography teacher education programs of HU University of Applied Science.



Theme 4: Scientific literacy in tertiary education and teacher education

This research theme concerns the question of how to foster scientific literacy in tertiary education, including that to the pre-service teacher and the future scientist. Within the Institute's academic context, this theme focuses on the mutual relationship between research and tertiary teaching and on investigating means to optimize it. We address the question of how to integrate recent knowledge from research in bachelor's curricula and tertiary teaching practices. How to support tertiary teachers' professional development and teacher training? How can faculty staff members develop means to recognize and address their students' needs in acquiring the scientific literacy they need? How to establish ongoing learning trajectories on scientific

literacy for the students in FI's master's programs History and Philosophy of Science (HPS) and Science Education and Communication (SEC), including the institute's teacher training programs? And how to address a similar challenge for the students in secondary education that our students might be teaching in future?

An important topic in future scientists' academic education is research integrity. In this theme we investigate what scientific integrity encompasses, how views on it have changed over time, how to educate future scientists with respect to scientific integrity, and how to strengthen an Open Science approach. The results inform Utrecht University's training initiatives on research integrity for faculty staff.

Research Methods

To investigate the research themes in this research program, FI's research focuses on a variety of research objects: individual students in lab settings or classrooms, cohorts of students, teachers, curricula, archives of scientific institutes, science communication in media, and scientific sources. These research objects are studied through a range of research methods.

For educational research, design research—which involves an iteration of cycles of design, field-testing, and evaluation—is used when the design of an intervention is a key part of the research (Bakker, 2018). In design research, a fundamental knowledge of the nature of the scientific and mathematical content is combined with insights in science didactics and pedagogy. Design research methods will be further developed, e.g., through giving implementation a more prominent place (design-based implementation research, see Fishman, Penuel, Allen, Cheng, & Sabelli, 2013). Lesson study is used to study teacher professional development and teacher behavior and beliefs (Dudley, 2011). It includes carrying out research with schools, educators and practitioners in co-design processes, rather than treating them as research objects.



For research on the history and philosophy of science, we study large digital databases of historical data, such as newspaper archives or institutional historical data collections. Data science and digital humanities offer new approaches to the research, which also might be of interest to educational research. As such, we want to cross methodological boundaries between the different disciplines that are represented in our group.

To increase our methodological repertoire and to enhance its scientific basis, we will explore new methodological directions that are possible thanks to new technological means, such as automated coding of qualitative data, single and dual eye tracking, bibliometrics, and learning analytics. Also, we wonder what we can learn from research methods in other fields, e.g., humanities and media studies, such as narrative reviews and ethnography, and further consider the transformative power of our inquiries for educational practice and societal issues. While doing so, we strive for an Open Science approach, in line with Utrecht University's research strategy.

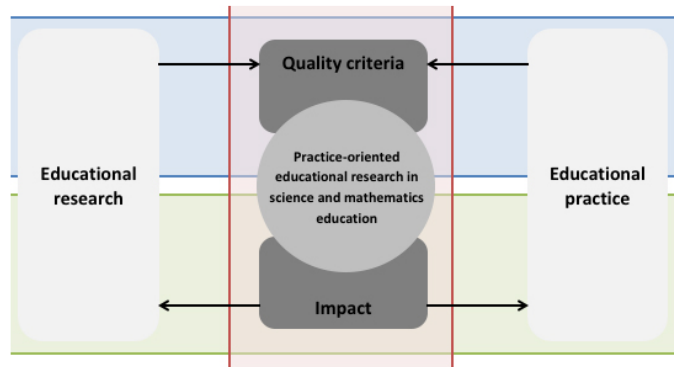
An important aspect of our methodological work concerns research integrity. In our methods, we ensure research quality with respect to ethics, integrity and privacy. Research

Virtual Reality in Vocational Education

Spatial insight is important in various professions, such as in the construction sector, and in daily life. One can acquire it in the three-dimensional world, but also with the help of apps on a two-dimensional screen. To what extent can virtual reality (VR) bridge both types of experiences and how can these learning experiences be integrated into a fruitful learning arrangement? To investigate this, the Building blocks app in the Digital Mathematics Environment is combined with a VR application developed by The Virtual Dutch Men. This learning arrangement is field-tested with students from the construction sector at Bouwmensen Utrecht.

Science Teachers as Postdocs

Practice-oriented educational research is considered an appropriate approach to bridge the research-practice gap in education. The potential impact of practice-oriented research on educational practice is considered high due to grounding in practice. However, there is limited empirical evidence to support this notion. Furthermore, quality and impact of practice-oriented educational research are often assumed to be interrelated, but research is needed to uncover their interrelatedness. The aim of this study is to contribute to closing the gap between research and practice by gaining insight in the interrelatedness of quality and impact of practice-oriented educational research in science and mathematics education (Groothuijsen et al., 2019)



studies will need approval from the Ethical committee and data will be stored according to the Data Management Plan's guidelines for safety and privacy. We further develop means to foster research quality and research integrity through courses for PhD students at Utrecht University and pre-service science and mathematics teachers (see theme 4)

Collaboration and Funding

In realizing our research aims and ambitions for the coming years, collaboration with partners is crucial. In these collaborations, partners play roles as co-designers and co-researchers, but also as channels for outreach and valorization, dissemination, and public engagement.

Within Utrecht University, the Freudenthal Institute closely collaborates with the different departments within the Faculty of Science and the Faculty of GeoSciences. The Teaching & Learning Lab is an important vehicle for teaching innovation within the Faculty of Science. At the

university level, similar collaborations are established with the Centre for Academic Teaching and with Educate-it, to connect university teachers' needs and research opportunities. FI takes part in the strategic theme Dynamics of Youth, and in Education for Learning Societies. For history and philosophy of science, the Institute collaborates closely with the Descartes Centre, of which FI professor Bert Theunissen is the present director. An important focus in this collaboration concerns research integrity: research on this informs the UU-wide course on research integrity, and vice versa. Utrecht University funding opportunities for educational research in the form of seed money and through the Utrecht Incentive Fund (Utrechts Stimuleringsfonds Onderwijs USO) have been successfully applied for.

At the national level, the Freudenthal Institute is a stakeholder in research in science education and communication, and as such collaborates with schools through the U-Talent network. In U-Talent, Utrecht University, HU University of Applied Sciences Utrecht and about 50 secondary schools in the region work together to

strengthen and enrich education through teaching, teacher professional development and research. U-Talent acts as a sparring partner in assessing teachers' needs and offers an excellent playing field for educational research. Within HU University of Applied Sciences Utrecht, the research groups on Science and Technology Education and Professionals' Mathematical and Analytical Abilities are close partners.

FI also participates in national networks, such as Ecent/ELWier, the Dutch Center of Expertise for Teacher Training in Mathematics and Science Education, the Interuniversity Centre for Educational Sciences ICO and the Association for Educational Research (Vereniging voor Onderwijsresearch VOR). We collaborate with national research and knowledge Institutes such as CITO, SLO, VSNU, and with other Dutch universities. The Utrecht University alliance with Eindhoven University of Technology and Wageningen University offers new opportunities to be explored. Joint projects with science museums such as Naturalis, Nemo and Boerhaave are planned, as well as with private partners such as publishers and software companies. For history and philosophy of science, close collaborations at the national level include

Huygens-ING (KNAW Humanities cluster), Museum Boerhaave, Teyler's Museum, Meertens Instituut, Vossius Centre, Rathenau Institute, and the Nederlands Instituut voor Beeld en Geluid.

National funding opportunities are provided by NWO (personal grants, National Research Agenda) and by the Nationaal Regieorgaan Onderwijsonderzoek NRO, including calls for part-time PhD research (Dudoc, Promodocs). The Sectorplan calls for Outreach Grants in Physics, Chemistry, Math and Computer Science also offer some opportunities, even if they are less research oriented.

At the international level, collaborations with a variety of international Institutes, European and worldwide, will be extended. This includes funded international projects, visiting professorships, and visits by guest researchers. We take part in international networks such as the International Centre for STEM Education (ICSE), and will intensify contacts with institutes similar to FI, such as the Department of Science Education, University of Copenhagen. Moreover, current collaborations with Institutes in Australia,

The Digital Mathematics Environment

The Digital Mathematics Environment (DME) is a digital online platform, developed by the Freudenthal Institute, for designing and running online activities for mathematics education. DME has been used in many research projects to study cutting-edge technologies such as handwriting recognition, automated feedback, and student modeling. A spin off company called Numworx (www.numworx.com) bridges research and educational practice and offers the newest tested innovations to schools in an accessible way and with affordable subscriptions. Utrecht University uses the DME as its platform for mathematics-related assessment.

China, France, Germany, Indonesia, Israel, Singapore, Surinam, and the USA will be extended. For history and philosophy of science, collaborations with UCLA, the University of Minnesota, the Max Planck Institut für Wissenschaftsgeschichte, and the Ruhr-Universität Bochum will be continued and intensified. EU programs (Horizon Europe, Green Deal, ERASMUS+) are important sources of funding. The Freudenthal Institute actively pursues the securing of these types of grants.

The Research Program in Practice

The following actions will be undertaken to put the research program into practice.

- **Multi-disciplinarity**
We will further exploit the Institute's multi-disciplinary strength through grant applications and research projects in which two or more research strands join forces. Research proposals and publications will be reviewed by colleagues with different disciplinary backgrounds.
- **The research base on science communication**
To improve the research base on science communication, and in view of the role that science communication can play in synergizing the Institute's research agenda, the Institute will seek collaboration with partners within the Faculty of Science (e.g., IMAU), within the University (e.g., Centrum voor Wetenschap en Cultuur) and outside (e.g., RIVM, KNMI, NEMO, Boerhaave Museum). Opportunities for a new chair for science communication or public engagement will be explored.
- **Research quality**
The procedures for improving quality will be fine-tuned. Research proposals will be peer-reviewed within the Institute's research committee and approved by the Science-Geo Ethics Review Board, practices concerning data storage and privacy guidelines will be further established.
- **Societal Relevance**
FI's high standards with respect to societal relevance will be further elaborated on in themes such as sustainability, scientific inquiry-based learning, and socio-scientific issues. The EU Coordination and Support Action calls form international vehicles to do so. Research initiatives will be taken that relate to current issues and trends, as with the recent "flash studies" on the effects of the pandemic lock-down, or in the Living Pasts project (<https://livingpasts.com/>) in which education, societal relevance and research are intertwined.
- **Viability**
To ensure the Institute's viability, attracting younger talent into permanent research positions is a necessity. Being successful in terms of funding acquisition is a precondition for this, and, therefore, a focus for the coming years. This includes personal grants.
- **Open Science**
In the light of the importance of open science, the Institute will deliver its research output in open access publications as much as possible and make its research procedures transparent. Furthermore, the FAIR principles (Findable, Accessible, Interoperable, Reusable data) will be respected, for example through the use of DANS (Data Archiving and Networked Services, <https://dans.knaw.nl/>).
- **Academic Culture**
FI highly values scientific integrity, as elaborated in the Netherlands Code of Conduct for Research Integrity. Attention to scientific integrity and ethics in curricula and PhD training will be structurally maintained. This attention fosters the awareness of the need to safeguard academic integrity. Learning the appropriate skills, following ethically responsible research practices, and recognizing ethical dilemmas and how to respond to them are addressed.

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