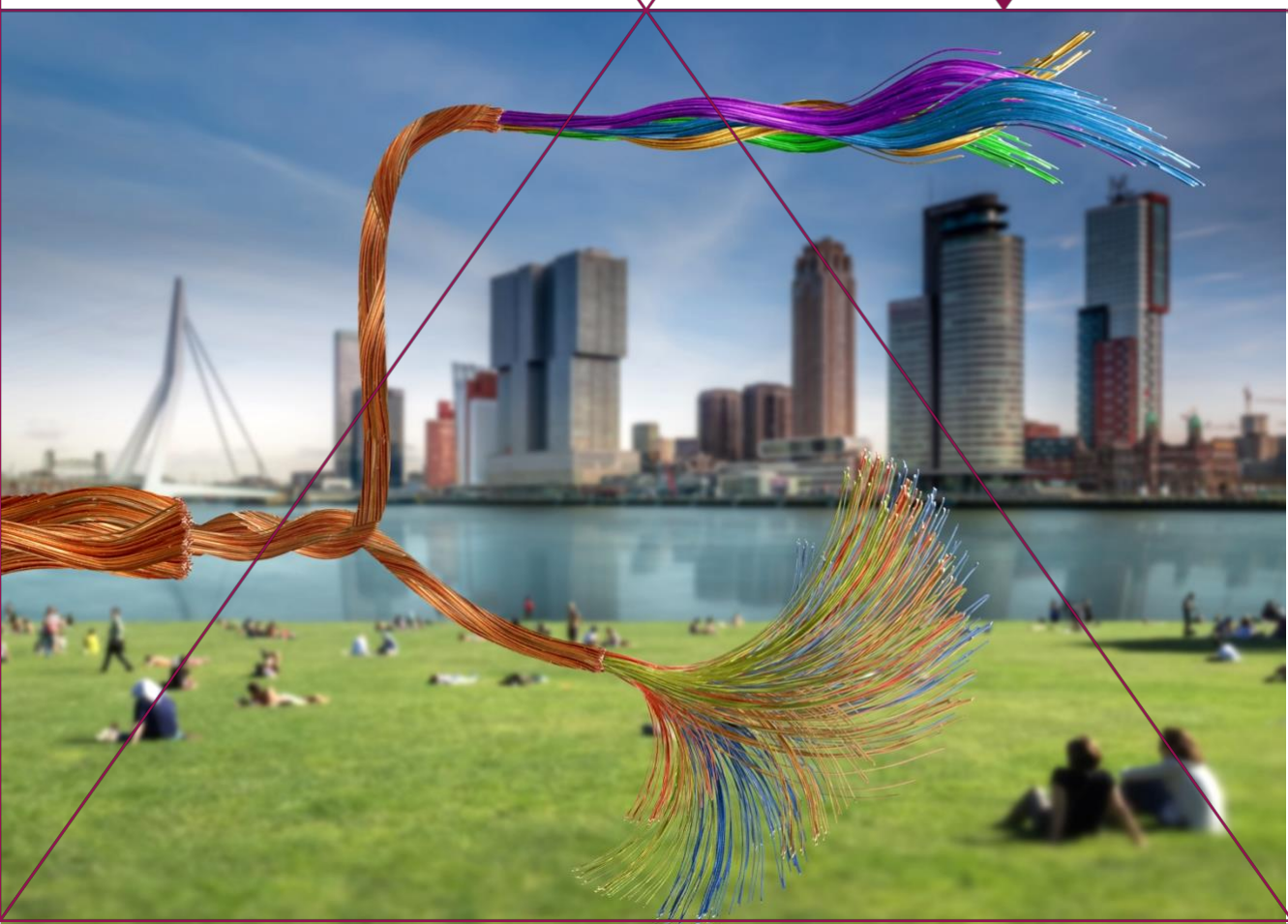
Awti Advisory council for science, technology and innovation

UNBOUNDED RESEARCH

PROMOTING INTERDISCIPLINARITY THROUGH TWO DISTINCT GOVERNMENT ROLES



Awti Adviesraad voor wetenschap, technologie en innovatie

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Unbounded research

Promoting interdisciplinarity through two distinct government roles

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Summary

Interdisciplinarity is crucial in research. It leads to scientific breakthroughs and opens the way for solutions to complex societal problems. In broad terms, interdisciplinary research means research which crosses the boundaries between different scientific disciplines. However, it is a concept that is open to different interpretations, such as integrating methods or theories drawn from at least two disciplines, or involving non-scientific partners in research.

Although research in the Netherlands is of a high standard and there are many interdisciplinary initiatives, there is no cause to rest on our laurels. Societal challenges demand a powerful Dutch research policy, which embraces interdisciplinary research. Given its strong starting position, the Netherlands could set an example in Europe in helping to forge a more effective policy on interdisciplinary research in the Netherlands and beyond.

But what is the government's role in facilitating interdisciplinary research, and what changes in policy are needed? To explore this, the Dutch Minister of Education, Culture and Science put the following question to the Advisory Council for Science, Technology and Innovation (AWTI): *How can the government encourage and facilitate interdisciplinary research more effectively, given the current challenges facing society?*

Recommendation: Recognise that the government has two distinct roles, and strengthen them

AWTI believes that research that spans individual disciplines should be strongly encouraged – not as an end in itself, but in order to provide answers to ever more complex societal and scientific questions. Interdisciplinarity is a very broad church, incorporating a diversity of forms including multidisciplinary and transdisciplinary research as well as citizen science. It is important to remove the barriers to all forms of interdisciplinarity. AWTI believes that an effective policy which embraces this diversity needs to more clearly define two distinct roles that should be fulfilled by government: 1) confidently creating scope for interdisciplinarity which arises from the scientific community and society, and 2) giving direction to and coordinating research aimed at addressing societal challenges.

Robustly fulfilling these dual roles will enable the government to facilitate the two mechanisms which give rise to interdisciplinarity. The first, bottom-up mechanism, is the result of an initiative by individual researchers or research teams, companies or organisations with a scientific or societal remit. This is crucial for exploring the limits of our knowledge, stimulating creativity and preparing for as yet unknown societal

challenges. The second mechanism is top-down: research funders – such as the government – tie resources to specific societal questions or themes and look for answers and solutions through targeted collaboration between scientists and society. This will bring focus and critical mass to interdisciplinary themes where there is a great need to develop knowledge.

A serious commitment to these two government roles will lead to an effective interplay between different actors and different kinds of interdisciplinary research. Monodisciplinary research continues to be essential, and that will not change.

Interdisciplinarity thus requires both bottom-up and top-down stimulation, but each mechanism calls for a different approach. Government does not have to do this alone: knowledge institutes, civil-society organisations, companies and individual researchers are all also working towards increased interdisciplinary cooperation. Precisely for this reason, AWTI recommends that adequate scope should also be created for bottom-up interdisciplinary initiatives.

AWTI puts forward four recommendations to turn this into practice.

- Facilitate bottom-up interdisciplinarity more wholeheartedly, and apply less conditions, starting by launching a new programme aimed at achieving excellence in small, interdisciplinary teams. Support this by making it easier for non-scientific actors to join other programmes.
- Make clearer choices to concentrate research on a limited number of interdisciplinary research platforms aimed at achieving societal transitions, creating a number of large, collaborative research platforms whilst at the same time removing fiscal barriers to collaboration.
- Promote interdisciplinarity through higher education. Support the development of teaching programmes which promote interdisciplinarity and reduce the relative impediments to setting up innovative, interdisciplinary programmes.
- Connect and apply knowledge about interdisciplinarity more effectively in policy and practice. Knowledge about interdisciplinarity is mounting nationally and internationally, but needs to be more embedded in and tied to the practice of researchers and policymakers.

1

Background: Confusion about interdisciplinarity impeding progress

Interdisciplinary research is key to achieving scientific breakthroughs, spawning new creative and radical ideas, and developing solutions to complex societal challenges. This is an area where the Netherlands performs fairly well. However, that is no reason to rest on our laurels: grasping opportunities to resolve societal challenges does not happen automatically. What can the government do?

1.1 Importance of interdisciplinarity undisputed, but often misunderstood

Interdisciplinarity is an uncontroversial element of research with scientific, societal and economic impact. Interdisciplinary research is associated with scientific breakthroughs, including discoveries that have been rewarded with Nobel Prizes.[1] But systematic studies of knowledge breakthroughs also show that interdisciplinary research leads to more creative and more radical ideas and produces greater societal impact.[2] Interdisciplinary research is even seen as indispensable for finding solutions to complex societal challenges.[3] Those challenges, whether they concern climate change, security or inequality, go beyond the confines of the traditional disciplines. Moreover, new combinations of knowledge are crucial for technological development and innovation in industry.[4] It is therefore no surprise that many organisations have long been calling for a stimulus for interdisciplinary research.[5]

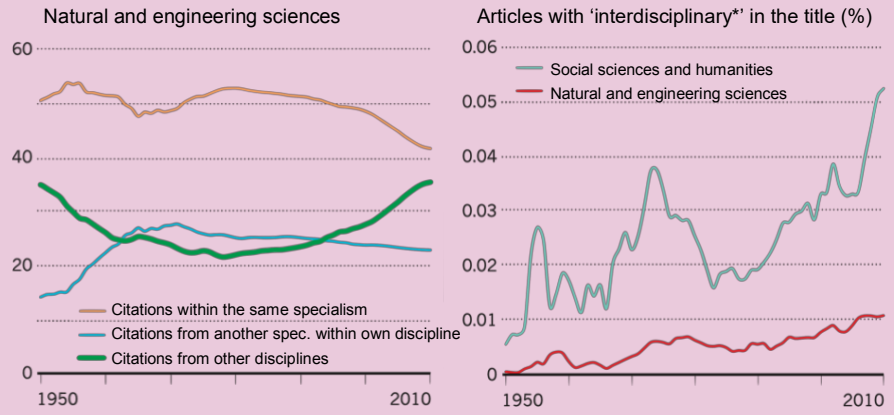
Despite the positive associations with interdisciplinary research, there is a lack of clarity about precisely what it means. Does it always imply the involvement of non-scientific partners? How much research is interdisciplinary? See Box ‘Increase in

1. Such as the combination of physics and chemistry, which led to the formalisation of the third law of thermodynamics, or of biology and physics which led to the discovery of DNA (Weingart & Stehr, 2000; Debackere *et al.*, 2020).
2. Different dimensions of interdisciplinary research are associated with differing degrees of innovation, ‘novelty’ and impact (Uzzi et al., 2013; Chen ey al., 2015; Larivière, Haustein & Börner, 2015; Van Noorden, 2015; Okamura, 2019).
3. There is a broad consensus in the literature that interdisciplinary collaboration is an essential ingredient of research which contributes to finding solutions to societal challenges (Hessels & van Lente, 2008; Jacobs & Frickel, 2009; Tromp, 2018; D’Este et al., 2019; Köhler et al., 2019; Dirks, 2021).
4. As long ago as the 1930s, Schumpeter (1934) highlighted the importance of combining existing knowledge in new ways to achieve innovation, and the combination of different forms of knowledge continues to be important for innovation today (Kaplan & Vakili, 2015).
5. Such as the OECD (1972), AWTI (2003) and WRR (2008).

interdisciplinarity?'. How is interdisciplinary research related to concepts such as transdisciplinary research, convergence research or open science? See Box 'Definition of interdisciplinarity' on page 11. For what purposes can interdisciplinary research be deployed? Some researchers warn against using the term 'interdisciplinary', urging the need to question which interests are at stake.[6] This lack of clarity makes developing effective policy for interdisciplinary research a complex undertaking.

Increase in interdisciplinarity?

Although it is exceptionally difficult to determine precisely,[7] the amount of interdisciplinary research does appear to be increasing.[8] This is illustrated in the figure below.[9] Internationally, there has been a measurable increase since the 1980s in the use of references from other disciplines in articles in the natural sciences (left-hand figure) There has been a similar increase in the social sciences since the 1990s (not shown in figure). There is also an observable increase in use of the term 'interdisciplinary' (right-hand figure).[10] There is no reason to suppose that these trends will be fundamentally different for the Netherlands.



6. Several authors express or refer to criticism of the term (Jacobs & Frickel, 2009; Evers *et al.*, 2015; Wilthagen, Aarts & Valcke, 2018).
7. There is little consensus about what the optimum measures are (Porter & Rafols, 2009; Wagner *et al.*, 2011; Leydesdorff, Wagner & Bornmann, 2019).
8. See Institute of Medicine (2004), Porter & Rafols (2009), Larivière & Gingras (2014) and Fortunato et al. (2018).
9. The figures are taken from Van Noorden (2015).
10. Wilthagen et al. (2018) outline the sharp increase in the Netherlands in the 1960s, the 1990s and the present day. (Klein, 1990; Lattuca, 2003).

Definition of interdisciplinarity

In this report, we use the term '**interdisciplinarity**' in a broad sense, to describe research which goes beyond the boundaries of individual scientific disciplines. The term 'interdisciplinary' incorporates a number of related terms which sometimes overlap. A brief description of these terms is given below.

Interdisciplinary research, in a specific sense, is the combination and integration of research methods, theories, epistemological schools, procedures and/or data from two or more scientific disciplines. This is related to **multidisciplinary research**, in which two or more scientific disciplines are individually involved in a research project, without any integration.[11]

Another way of bridging the boundaries between scientific disciplines is through research collaboration with non-scientific or civil-society partners. The term **transdisciplinary** is used to describe this kind of research, which draws on the knowledge, skills and experiences of partners from outside the world of science.[12]

Convergence research is a term originally from the United States. It describes research in which several disciplines are combined to address complex societal and scientific questions. Convergence research is sometimes regarded as an 'advanced' form of interdisciplinary research, involving a 'deep' integration of different disciplines to create a new discipline.[13]

Citizen Science is research that is carried out wholly or partly by citizens or non-professional scientists.[14]

Open science is a movement which seeks to make the scientific process more transparent and to improve the dissemination of the results throughout the whole of society. 'Open access', which affords free access to scientific articles, is often regarded as a component of open science.[15]

11. Based on various publications (Klein, 1990; Tress, Tress & Fry, 2005; Larivière & Gingras, 2014; Van Noorden, 2015; Wilthagen, Aarts & Valcke, 2018; Te Velde, Den Hertog & Ysebaert, 2019; Glanzel & Debackere, 2021).
12. This description is based on numerous publications (Klein et al., 2000; Tress, Tress & Fry, 2005; Huutoniemi et al., 2010; Mauser et al., 2013; Slot, 2021).
13. See National Research Council (2014) and the National Academies of Sciences, Engineering, and Medicine (2019).
14. See Koens et al. (2020, p. 37) and https://waag.org/nl/tags/citizen-science
15. See the AWTI report 'Dare to share' (AWTI, 2016) and the UNESCO recommendations on open science (UNESCO, 2021).

1.2 Dutch research: high quality, progressive policy

Dutch research is of high quality: the Netherlands scores above average in international rankings, benchmarks and other research ratings, despite only average investments in research and development.[16] It is important to nurture the strengths within the current system. It is not uncommon for the Netherlands to be cited as an example of innovation in science,[17] a reputation achieved partly thanks to its research policy and its dynamic research practice.

Dutch research policy is characterised by a hands-off, indirect approach by the government, with mediating organisations operating between government policy and research institutes, such as the Royal Netherlands Academy of Arts and Sciences (KNAW), Universities of the Netherlands (UNL, formerly the Association of Universities in the Netherlands, VSNU) and the Dutch Research Council (NWO).[18] This has resulted in a relatively stable and coherent research policy, which strikes a degree of balance between targeted and general research, fundamental and applied research, strategic and unbound basic research.

Research in the Netherlands is also relatively dynamic. The government espouses the importance of interdisciplinary research in its science and innovation policy, especially in communications.[19] In addition, (interdisciplinary) research institutes are being set up, often affiliated with or part of existing knowledge institutes.[20] A number of partnerships have also arisen in recent years between universities[21] and between universities and universities of applied sciences.[22] This provides impetus to interdisciplinary collaboration. Recent policy aimed at tackling societal challenges also encourages interdisciplinary research. The introduction of the Mission-driven Top Sectors Research and Innovation Policy (MTIB) and the National Research Agenda (NWA) are good examples of this.

16. This is evident from several studies (AWTI, 2014; Schwab et al., 2019; Koens et al., 2020).
17. The Institute of Medicine published a report in 2004 (2004) in which the Netherlands was used as a case study. The Netherlands also came out relatively well in an international comparison carried out by AWTI (Menenti *et al.*, 2021). This picture is supported by other sources (CFA, Technopolis Group, & NIFU, 2016; Baker, 2017; Mitchell, 2021; Woolston, 2021).
18. This was described by Van der Meulen and Rip (1998) and repeated in more recent publications (CFA, Technopolis Group, & NIFU, 2016; Bongers et al., 2021).
19. The Vision for Science 2025 (Wetenschapsvisie 2025), for example, expects to see innovation coming mainly 'from multidisciplinary research'. The document 'Curious and committed. The value of science', published by the Dutch Minister of Education, Culture and Science, and the Strategic Agenda comment on the increasing importance of interdisciplinary research and the growing interest in it among students.
20. See Appendix 2 for an overview.
21. Leiden-Delft-Erasmus Universities (www.leiden-delft-erasmus.nl), Convergence Alliance of TU Delft, WUR and Erasmus MC (convergence.nl), Strategic alliance of UU, UMCU, WUR and TUe (www.ewuu.nl/), and the 4TU partnership of TU Delft, TU Eindhoven, Twente University and Wageningen University & Research (www.4tu.nl).
22. For example, the University of the North (https://www.universiteitvanhetnoorden.nl/)

These programmes each influence research in the Netherlands in their own way. The discussions around open science and on recognition and rewards of researchers are further examples of the research dynamic in the Netherlands, which also links to interdisciplinarity.

Example of interdisciplinarity: transdisciplinary research at RegMed and the Dutch Kidney Foundation (Nierstichting)

Regenerative Medicine Crossing Borders – RegMed XB – is an international multidisciplinary partnership in virtual form. Its aim is to generate knowledge and results which cross boundaries. Health funds and patient organisations work together with scientists, the private sector and public authorities in the Netherlands and Flanders. Together, these four pillars (research, industry, public authorities and civil-society partners, in this case represented by patient organisations) constitute a 'quadruple helix'.

This partnership has enabled researchers to grow mini-kidneys in the laboratory. These make it possible to model a range of diseases, making them easier to study. In April 2021, RegMed received 56 million euros from the National Growth Fund. This money will be spent on staffing a pilot factory to manufacture the various materials needed for kidney cultivation on a larger scale, such as biomaterials, stem cells, micro-tissues and macro-tissues.

1.3 Grasping opportunities does not happen automatically

Dutch research, then, is of high quality; but there is no cause for the Netherlands to rest on its laurels. Given its strong starting position, the Netherlands could set an example in Europe in helping to forge a more effective policy on interdisciplinary research in the Netherlands and beyond. This could also enable researchers in the Netherlands to benefit from international opportunities.[23] Setting an example will require the Netherlands to continue to lead in research policy and practice. Partly for this reason, there are calls from several quarters for the knowledge and innovation policy to (further) encourage

23. The ERC was originally forged partly on the model of the Dutch Innovation Impulse (now the Talent Programme), and Dutch researchers are still very closely affiliated to the ERC (see https://www.rathenau.nl/nl/wetenschap-cijfers/werking-van-de-wetenschap/excellentie/toekenningen-erc-land-universiteit-en)

interdisciplinary research.[24] Interdisciplinary research is often put forward as part of the solution, but sometimes, conversely, as part of the problem.[25]

There are moreover a number of societal challenges which have enormous implications for employment, training and education.[26] Topical examples include climate change, (cyber) security, housing and the coronavirus pandemic. These challenges demand explicit attention for interdisciplinary collaboration, because it is only rarely that solutions arise within individual research disciplines.[27]

1.4 Request for advice: How can the government promote interdisciplinarity more effectively and more permanently?

Given the lack of clarity surrounding the term and the upcoming societal challenges, it is by no means self-evident what role the government should play if it wishes to (continue) promoting interdisciplinary research. It is also unclear what policy and other changes will be needed and who should take the initiative to make them. It is against this backdrop that the Minister of Education, Culture and Science asked the Advisory Council for Science, Technology and Innovation (AWTI) the following question:

How can the government promote and facilitate interdisciplinary research more effectively, given the existing societal challenges?

AWTI first explored what interdisciplinarity entails (see Box 'Definition of interdisciplinarity' on page 11). A policy analysis was also performed to determine how policy currently influences interdisciplinary research. The factors which promote and inhibit interdisciplinary research were also analysed (see Appendix 3). Furthermore, an inventory was compiled of interdisciplinary projects, programmes and institutes (see various Boxes throughout this report and also Appendix 2). The insights gained through these analyses were discussed during an expert meeting in the autumn of 2021. The Council then studied what role the government can play in promoting interdisciplinarity. Finally, the Council determined what policy modifications are needed to enable the government to fulfil that role more effectively. Appendix 1 describes in more detail how

24. See Evers et al. (2015), Didier & Darbellay (2016), Ball (2019) VSNU et al. (2019) Van de Walle & Saso (2020) and the European University Association (2021).
25. In addition to positive associations, interdisciplinary collaboration is also sometimes regarded as hype or as a meaningless label. Interdisciplinary research can also be seen from a different perspective as constraining unbound basic research. The term is also sometimes used as a means of pushing through very different changes (e.g. organisational) (Evers et al., 2015; Wilthagen, Aarts & Valcke, 2018; KNAW, 2019; Zwaan, 2019).
26. Examples include climate change, the pressure on the care system, concerns about digital security and growing inequality (AWTI, 2020).
27. This is emphasised by several authors (Menken et al., 2016; Tromp, 2018; Putters, 2021).

this report was created, and Appendix 3 contains a list of the experts to whom we spoke in preparing this report.

In publishing this report, AWTI is seeking to clarify the discussion about interdisciplinary research and offer pointers for more effective policy. This would help the Netherlands act as an example for interdisciplinary research and at the same time achieve maximum societal impact.

Project group

This report was prepared by a project group consisting of Council members Ellen Moors (chair), Roshan Cools and Tim van der Hagen, and staff members Chris Eveleens, Justien Dingelstad, Kathleen Torrance and Anne Nelissen.

Layout of the report

Chapter 2 opens with the central message of this report: recognise that the government has two distinct roles, and strengthen them. Chapter underpins this message by showing why this distinction is necessary, what is currently not working and where the policy could be improved.

Chapter 3 puts forward recommendations suggesting what targeted changes the government and other actors can make to instil the difference in government roles more effectively in policy and practice.

2

Recommendation: Recognise that the government has two distinct roles, and strengthen them

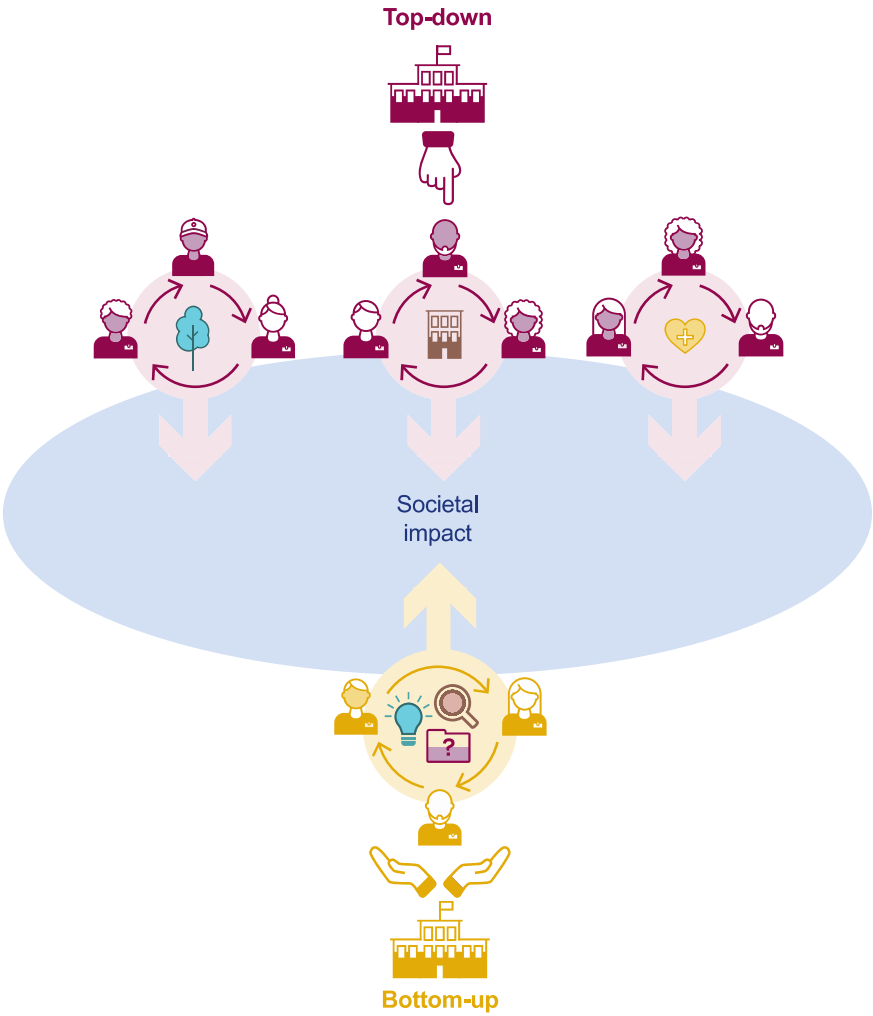
Research which extends beyond individual disciplines should be wholeheartedly encouraged – not as an end in itself, but because of the growing need of being able to provide an answer to complex societal and scientific questions. AWTI recommends that obstacles to interdisciplinary collaboration be removed. This requires a clearer definition of two distinct government roles: one of creating the necessary confidence and space for interdisciplinary collaboration which is initiated by the research community in a bottom-up process; and one of giving direction to and coordinating research to address societal challenges, most of which will require an interdisciplinary approach (top-down).

First of all: traditional disciplines and disciplinary research are still important. However, scientific, societal and economic progress also demand different forms of interdisciplinarity. AWTI sees two key mechanisms for achieving this.[28] The first is a **bottom-up** process: here, interdisciplinary research takes place on the initiative of individual researchers or research teams, companies or organisations with a scientific or societal object. This is crucial for exploring the limits of our knowledge, and for creativity. The second mechanism operates **top-down**: research funders – such as the government – tie funding to specific societal challenges or themes, and thereby promote the interdisciplinary collaboration that is often needed to address those challenges. This mechanism is just as crucial, because it brings focus and critical mass to bear on themes where knowledge urgently needs to be developed.

To promote both mechanisms, AWTI recommends that the government assume two distinct roles. If it fails to do this and the two roles remain intertwined, this will frustrate research and constrain the bottom-up mechanism, in particular. Clarity regarding these roles will also help remove frequently cited obstacles to various forms of interdisciplinarity (e.g. discipline-based career paths, discipline-specific knowledge institutes and discipline-specific funding). This chapter substantiates this recommendation; chapter 3 explains how it can be put into practice.

28. This distinction is in line with a number of other sources (Didier & Darbellay, 2016; Bourguignon, 2019).

Recognise two distinct roles for the government and strengthen them to promote interdisciplinary research



2.1 Promoting interdisciplinarity demands two distinct government roles

AWTI aims to inject some clarity into the debate about policy on interdisciplinary research by defining two distinct roles for the government. These roles are of long-term relevance

in promoting research across disciplines, and involve both facilitating bottom-up collaboration and top-down steering.

This distinction is necessary because interdisciplinary collaboration is a key ingredient of research, but its precise significance and nature will vary depending on the type and purpose of that research. Exploratory research in which scientists work alongside non-scientists, for example to reflect on the future of cities, requires policy that allows scope for scientists to set their own agendas but in which there is room to involve civil-society stakeholders.[29] The situation is different when interdisciplinary research is used to achieve fundamental breakthroughs in science, where the main requirement is for long-term funding of small groups of top scientists. Different again is the need to provide specific answers to current societal challenges; this demands research which brings together different actors from society and from a variety of scientific disciplines to focus on a particular challenge. That implies high transaction costs, a need for organisational skills and leadership from the government.

The different forms taken by interdisciplinarity mean that the government cannot promote this type of research with a broad-brush approach. What works well for one kind of research may lead to unintended consequences elsewhere. Conversely, it is not feasible to aim for a completely customised approach, nor is it wise to redefine the role of the government for each new form of interdisciplinarity. The field of interdisciplinary research is in a continual state of development, both as regards research practice and the relationship between research and society. Science is evolving, and this gives rise to new interdisciplinary domains and disciplines. As a result, promoting interdisciplinary research is like aiming at a moving target.[30]

The distinction between the two government roles is essential because interdisciplinary research often requires two sets of opposing actions. Top-down measures to promote interdisciplinarity can stand in the way of the bottom-up mechanism (see section 2.2). The mechanisms are complementary, and both are indispensable for a well-functioning research system.

29. An example of this is the Urban Futures Studio at Utrecht University. See https://www.uu.nl/en/research/urban-futures-studio
30. The present disciplines are often the result of interdisciplinary initiatives and provide necessary knowledge (Burggren et al., 2017). However, new knowledge opportunities and needs often lie in different domains, between existing disciplines. Once these new initiatives have become institutionalised, the process of turning a new field of knowledge into a discipline begins. An interdisciplinary approach is then once again needed in order to exploit new opportunities.

Examples of bottom-up interdisciplinarity

Institute for Advanced Study

The University of Amsterdam founded the Institute for Advanced Study (IAS) in order to offer outstanding researchers a place where they can work collaboratively on complex challenges, free from the constraints of disciplinary boundaries. The Institute is focused on complex, adaptive systems. Many of today's societal challenges contain elements of these systems (such as tipping points and resilience). Research on the dynamic of these complex systems is therefore crucial for improving the effects of envisaged interventions and strategies. The IAS develops new methodologies with a view to bridging the gaps between different disciplines (e.g. mathematics, sociology, economics, political science, law).

ERC Synergy Grants

Synergy Grants, awarded by the European Research Council (ERC), generate scientific breakthroughs by combining complementary skills, knowledge and resources. The grants target ambitious research questions in any field. This requires collaboration between researchers from a range of disciplines. Two examples are given below of recent projects funded by Synergy Grants, in which Dutch knowledge institutes participate.

- **NanoBubbles** This project combines approaches from the natural, engineering, social and life sciences to research how erroneous claims can be rectified. It does this by studying the peer review system and carrying out replication experiments. As well as helping progress the science of nanobiology, the project also helps restore faith in science by looking critically at how errors arise and rectifying them.
- **Carbocentre Synergy Team**. This project researches complex carbohydrates, among the most commonly occurring and diverse molecules on earth. The synthesis, modification and breakdown of carbohydrates is governed by enzymes, but not much is yet known about these. The research team develops new chemical compounds, known as 'activity-based probes', to visualise, modulate and understand how these enzymes function. This involves the use of sophisticated computer analyses. This technique spawns important biological insights, thanks to the combination of computer science and organic chemistry. Those insights can help in the development of drugs to treat diseases such as cancer and viral infections, but also in the development of green energy.

The first role: a government which offers scope and facilitates

Interdisciplinary collaboration can mean the integration of scientific disciplines to allow radical and surprising breakthroughs which can in time have a major scientific and societal impact, in unexpected ways and combinations (see the examples in Box 'Examples of bottom-up interdisciplinarity' on page 23). Promoting this kind of research requires a government which convincingly creates a space within which researchers are able to dismantle the barriers between scientific disciplines and explore new fields of knowledge. The government adopts a very hands-off stance as regards the content and thus promotes bottom-up interdisciplinarity in the right way, i.e. with full confidence. The government's own objectives are not the central focus, and research goals often have the character of 'high risk, high gain': the risk of failure is high, but so are the rewards of success.

This facilitating role by the government gives researchers[31] the right incentive to carry out high-risk but potentially groundbreaking research. The areas in which they do this are by definition unknown in advance; that is determined by the researchers themselves. Research proposals therefore have to be assessed based on the potential rewards, notwithstanding the attendant risks. There must also be room for uncertainty and failures.

The second role: a government which gives direction, coordinates and is engaged

Interdisciplinary collaboration also means integrating knowledge from diverse fields of knowledge in order to provide demand-led answers to topical societal questions. The recent government Coalition Agreement makes clear the urgency of these societal challenges.[32] Promoting this kind of research requires a committed government which organises research and innovation around existing societal issues. One way in which the government can give direction is through the Coalition Agreement, for example by setting out a vision for the future, or through societal missions.[33] The government is also an active member of research consortia at national and regional level (see the example 'Room for the River' in Box 'Example of top-down interdisciplinarity' on page 12).

If the government takes on this role, this will create a clear action framework for other parties. The government is one of the demand-side parties in relation to topics for which it is responsible, such as care, safety, education and infrastructure. It is the 'client' of interdisciplinary research, and together with other civil-society organisations or

31. The term 'researchers' is used here in a broad sense, to include researchers at universities, applied research institutes, practice-oriented researchers, in companies and in wider society.
32. Omzien naar elkaar, vooruitkijken naar de toekomst ('Looking out for each other, looking ahead to the future'). Coalition Agreement 2021 – 2025 (VVD, D66, CDA & ChristenUnie, 2021)
33. See AWTI report 'Strengthen the role of science, technology and innovation in societal transitions' (AWTI, 2020).

companies is looking for new insights and solutions. And in fulfilling this role, the government develops as the research process evolves.

Example of top-down interdisciplinarity[34]

Room for the River: interdisciplinary collaboration keeps the Netherlands dry

The national 'Room for the River' programme ran from 2000 to 2019. Its aim was to improve both water safety and the quality of the landscape. Measures were taken at 34 different locations in the Netherlands to give more space to the great rivers. The programme is regarded as especially innovative due to a number of characteristics which impinge directly on interdisciplinary research:

- From the start, all manner of different disciplines were involved: river experts (hydrologists), spatial development specialists, ecologists, civil engineers, cultural historians, administrative lawyers and soil experts.
- A number of key figures (several administrators, member of the Programme Office and the Spatial Quality Cluster) played an active role in promoting common leadership. These 'boundary spanners' were active at the interface of their organisations/organisational units in seeking to improve the links with the local community and stakeholders.
- Interactive design studios were also involved in the programme. During the planning phase, several stakeholders (civil-society organisations, administrative partners, etc.) were invited to come up with powerful and appealing designs for spatial quality, using methodologies such as informal roundtable sessions and participative design.

Fulfilling both roles with conviction will lead to effective interplay

The government thus has two key roles to play in promoting interdisciplinarity: one passive and the other active. Fulfilling these two roles with conviction will lead to an effective interplay between different actors and types of interdisciplinarity. Monodisciplinary research continues to be essential, and that will not change.

To begin with the first point: fulfilling these two roles with conviction will engender the right synergy in research. The government's role in creating scope will generate a reservoir of knowledge, on which public authorities and other parties can draw in addressing new societal challenges, opening the way for more precise and faster solutions. An example is the development of the Covid-19 vaccines (see Box 'The origin and development of Covid-19 vaccines' below). Thanks to the free space created by the government, there is

34. Another example of top-down interdisciplinary research is the work of the United Nations Intergovernmental Panel on Climate Change (IPCC).

a long tradition of research on messenger ribonucleic acid (mRNA). When the coronavirus outbreak grew into a pandemic, targeted government steering enabled that knowledge to be deployed rapidly to help combat the pandemic through the development of vaccines.

The origin and development of Covid-19 vaccines

As long ago as the 1980s, researchers began experimenting with messenger ribonuclease acid (mRNA) and fat cells. That research built on earlier research on liposomes (in the 1970s) and on mRNA (discovered in the 1960s). The cells themselves produced proteins, and researchers realised that this property meant that mRNA might be able to be used as a medicine.[35] The antiviral drugs used up to that point were based on mimicking a virus, giving the human immune system the opportunity to 'practise' and so giving the body better protection against a genuine infection. By contrast, mRNA is able to convey instructions to cells to begin making fragments of the actual virus on which the body's immune system can practise. This proved to be a much more flexible way of 'training' the human immune system, because cells were able to make the necessary virus fragments themselves. This marked the start of a fundamental change in vaccination technology.[36] Many experiments with mRNA followed in university laboratories, which ultimately led to the ability to chemically modify mRNA. In the 1990s, pharmaceutical companies began developing drugs (antivirals, but also drugs for the treatment of cancer) using this technique. The Covid-19 vaccines were ultimately developed by spin-offs of these pharmaceutical companies, such as Moderna and BioNTech, working in collaboration with researchers.

Traditional disciplines remain as important as ever, and therefore need to remain a central element in the academic system. Today's monodisciplines arose from the successful interdisciplinary fields of the past, with examples such as molecular biology, (cognitive) brain science or environmental science. Over long periods of time, there is specialisation within disciplines, new disciplines emerge and split off from them, and disciplines are integrated (see Box 'New disciplines emerge from integration of other disciplines' below). This process of splitting and coming together of disciplines is driven by all manner of social processes, such as the closure of a particular research domain to

35. See Dolgin (2021) for a description of the origin of mRNA vaccines, on which this Box is largely based.
36. See also the explanation (in Dutch) of the development of mRNA vaccines by Robert Dijkgraaf in the BNNVARA TV programme 'Het Wetenschappelijk jaaroverzicht' ('The Annual Scientific Review') (23 December 2021).

outsiders, abandonment of a research field due to dissatisfaction with the results, or the claiming of a specific research area.[37]

New disciplines emerge from integration of other disciplines

Biotechnology is the result of the integration of biology and chemical technology. Similarly, the combination of cell biology and biochemistry gave rise to molecular biology. Molecular biology, chemistry, optics, micro-technology, combinatorics and bioinformatics together led to the emergence of genomics. The rise of systems biology was made possible by the combination of genomics with other 'omics', with applied engineering, design-thinking, behavioural control theory and complex systems.[38] Nanobiology, the combination of disciplines including physics and biology, is another example of the emergence of a new discipline.

In addition, established disciplines and monodisciplines have an unparalleled ability to understand and structure the world. However, the inwardly focused social dynamic of disciplines limits the choice of questions that can be asked and means that preference is given to dominant theories and methods (epistemology). Knowledge that does not fit readily into established disciplines is then given little scope, bringing the risk of undermining innovation. Knowledge which emerges from disciplines must therefore be combined and opened up for discussion through collaboration between disciplines. Only then will researchers push the boundaries and achieve progress and generate new ideas. Disciplines offer a stable basis from which they can seek out those boundaries. An interdisciplinary approach is therefore required in order to help disciplines progress, but established disciplines are equally necessary for interdisciplinary collaboration.[39] They do not replace each other, but complement each other.

2.2 Confusion of roles mainly impedes bottom-up initiatives

The Netherlands is already doing a great deal to promote interdisciplinarity, and a good deal of interdisciplinary research also takes place. However, those promotion efforts are too uniform. The policy could be more powerful and more effective if there were a clearer distinction between the two government roles. Mixing the two roles can lead to complexity and lack of clarity in the criteria used to assess interdisciplinary research. This mainly impedes bottom-up initiatives; this is explored further in this section.

37. See e.g. Van Baalen & Karsten (2002)
38. (National Research Council, 2014; Vugteveen, Lenders & Van den Besselaar, 2014; Coccia, 2020)
39. This synergy is also stressed by Didier and Darbellay (2016)

Interdisciplinary research already taking place partly thanks to existing policy

The exploratory study carried out by AWTI in preparing this report shows that the Netherlands is quite active in promoting interdisciplinary research in a number of ways.[40] The national 'Room for the River' programme is a good example of interdisciplinary collaboration aimed at reducing the Netherlands' vulnerability to flooding (see Box 'Example of top-down interdisciplinarity' on page 23).[41] The National Research Agenda (NWA) is a relatively new instrument designed to bring society and science closer together and contribute to interdisciplinary collaboration. The Dutch Research Council (NWO) programme 'Socially Responsible Innovation' and the Talent programme have also spawned important interdisciplinary research.

Examples of role confusion which exacerbates frustration

Although both government roles are implicitly encapsulated in the existing policy, analysis of that policy shows that in practice the distinction between them is sometimes blurred. As a result, extra conditions and expectations are often imposed for research, which are not always achievable. A few examples will illustrate this.

The first example is the document Vision for Science 2025.[42] Chapter 1 of that Vision ('Excellent science') emphasises (in Dutch) the importance of unbound basic research as a breeding ground for scientific breakthroughs in the future (page 18). What those breakthroughs will be is unknown: all scientific disciplines must be able to contribute to them. This implies a bottom-up approach to interdisciplinary research. However, in the practical implementation of this vision it is proposed that the research assessment criteria be adapted so that more weight is given to the contribution the research makes to the *present* public debate and to policy development: assessment criteria which mainly favour a top-down approach.[43] They can stifle unbound exploratory research at birth.

We find a similar mixing of roles in the 2019 document published by the Minister of Education, Culture and Science, 'Curious and committed. The value of science'. In this document, the Minister expresses a desire to promote public-private research partnerships with a view to advancing societally relevant research. This implies the demand-led, top-down promotion of interdisciplinarity. However, the Minister also says

40. In particular, a summary and analysis of Dutch policy and a background study by Technopolis in which the Dutch situation was compared with that in other countries (Menenti et al., 2021).
41. For an overview of the programme, see https://www.rijkswaterstaat.nl/water/waterbeheer/bescherming-tegen-het-water/maatregelen-om-overstromingen-te-voorkomen/ruimte-voor-de-rivieren#nieuwe-aanpak
42. Prepared by the Dutch Ministry of Education, Culture and Science (2014).
43. This intermingling can also be found in the views on individual researchers: they must be given the space to carry out excellent research, suggesting a bottom-up mechanism; but once again, societal impact is used as an important criterion for awarding research funding.

that, 'I do think it is important that researchers allow themselves to be led by questions that are *scientifically relevant*, because scientific advances will then be accompanied by innovation and economic growth [emphasis added by AWTI].[44] Although there are occasionally situations in which these combinations do arise, in most cases this requires research proposals which are 'as rare as a five-legged sheep'.

Finally, we see an increasing intermingling of scientific and societal focus in the three basic research programmes sponsored by the Dutch Research Council: 'Veni Vidi Vici' (Talent Programme), 'Gravitation' and 'Open Competition'. These programmes provide an important (financial) incentive for bottom-up interdisciplinarity; however, they impose an ever-increasing number of conditions for the awarding of funding, lending them the character of top-down policy.

The international survey study showed that other countries are better at combating the mixing of these government roles.[45] The European Union framework programme, for example, offers clarity through a 'pillar structure'.[46] Finland provides clarity by separating off funding of demand-led research under the Strategic Research Council.[47]

Active promotion taking over from hands-off approach: bottom-up interdisciplinarity losing out

The government can support interdisciplinary cooperation in two ways, and each role needs to be fulfilled in its own way. One role (bottom-up) requires the provision of funding and trust, but beyond that a hands-off approach from the government. In the other role (top-down), the government creates clear frameworks, offers coordination, participates actively, steers, etc. It appears as if the government is currently seeking to promote interdisciplinarity primarily from this active role. The diverse character of interdisciplinary research is pushed to the background and the dual role of the government consequently disappears from the picture. The result is often that supplementary conditions and expectations are imposed for research funding. This can benefit the top-down mechanism, but at the expense of bottom-up interdisciplinarity.

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44. 'Curious and committed. The value of science' (Ministerie van Onderwijs, Cultuur en Wetenschap, 2019, p. 47).
45. See the description of the various case studies in Menenti *et al.*, 2021).
46. In 'pillar 1', labelled 'excellent science', there is ample room for bottom-up interdisciplinarity on any chosen theme. In 'pillar 2', which is described as 'mission-oriented', there is a clear focus on societal challenges and industrial opportunities.
47. The Strategic Research Council is a separate entity of the Academy of Finland, which promotes strategic research.

2.3 Distinct roles help in tackling obstacles

The distinction between the two government roles is helpful in tackling the frequently cited obstacles to interdisciplinary cooperation. Extensive scientific research shows that those obstacles still very much exist, including in the Netherlands, despite its good track record. Appendix 3 summarises these obstacles based on existing research, updated and tailored to the Dutch situation. The most pressing and frequently cited obstacles to interdisciplinary research are as follows:

- The career paths of individual researchers are largely discipline-specific.
- Researchers possess insufficient skills or lack a common language to enable them to work fruitfully in interdisciplinary teams.
- Knowledge institutes are largely organised around single disciplines, thereby impeding cross-fertilisation and throwing up administrative barriers.
- Funding, rewards and evaluation of research activities are excessively based on monodisciplinary quality standards.[48]

These are frequently cited obstacles, but their precise nature varies, depending on the type of interdisciplinarity envisaged. The obstacles to involving non-scientific actors in research (transdisciplinary research or open science) are very different from those impeding the integration of theoretical frameworks or methods from different disciplines in order to achieve scientific breakthroughs. Consequently, different approaches are also needed. Otherwise, promoting one form of interdisciplinarity can throw up additional barriers to another form. Several of the interviewees consulted for this report, for example, stress that the present policy of the Dutch Research Council (NWO) aimed at promoting excellence in research in the form of the Talent Programme (the Veni-Vidi-Vici fairs) act as an obstacle to involving non-scientific actors and/or the ability to respond directly to societal challenges.[49] Others, by contrast, argue that the Talent Programme is the right place for interdisciplinary cooperation aimed at achieving scientific breakthroughs beyond the confines of individual disciplines.[50]

Three aces for promoting interdisciplinarity in its many forms

The good news is that the Netherlands has three key aces in its arsenal for promoting interdisciplinarity in its many forms. Precisely how those aces are deployed depends on the two distinct government roles. These aces, which are already being deployed to some extent, are as follows:

48. See also Rinnoy Kan Commission (2020).
49. See also Scholten et al. (2021).
50. Cf. e.g. https://erc.europa.eu/news/impact-erc-research-confirmed2020

- **Use of collaborative platforms and a common infrastructure**
  People with a wide range of expertise need to be able to find and understand each other, without any predetermined restrictions as to where that collaboration should or will lead. To facilitate these meetings – especially in the pre-development phase of interdisciplinary research – time, money and (physical) space must be available with no specific disciplinary label. The government can organise this top-down, but such structures also often emerge in a bottom-up process (see Appendix 2).
- **Preparing for interdisciplinarity in higher education**
  Successful interdisciplinary research begins in the education system. If higher education establishments include interdisciplinary research in their teaching, this will remove a major impediment. We are seeing steady growth in educational programmes which span the boundaries between the arts, exact sciences, social sciences and medical science. Higher education programmes are determined partly bottom-up, through the initiatives of lecturers/researchers and student preferences. But there are also top-down influences through the accreditation and funding of programmes.
- **Development of knowledge and skills around interdisciplinary research**
  Interdisciplinarity also benefits from the development of knowledge about the subject, Including the skills to organise, lead and assess interdisciplinary research. A great deal of knowledge and experience has been built up in recent years about interdisciplinary research, and a great deal of experience has also been gained in promoting and assessing this kind of research.[51] However, this knowledge is still fragmented and insufficiently connected to practice. Strengthening the links between research and practice regarding interdisciplinarity in a broad sense will help to better inform both policy and practice.

Chapter 3 explains how AWTI believes these aces could be deployed in the light of the two distinct government roles.

51. See e.g. Bammer (2013) and https://www.shapeid.eu/ and https://researchonresearch.org/

3

Four recommendations for promoting interdisciplinarity more effectively

AWTI recommends that the government draws a clearer distinction between two roles in promoting interdisciplinarity, and pursue those roles with strength. The government does not have to act alone in promoting interdisciplinarity: knowledge institutes, civil-society organisations, companies and individual researchers are also fully engaged. Precisely for this reason, AWTI recommends facilitating bottom-up cooperation in combination with a top-down focus on societal themes; this will lead to more effective promotion and thus to more societal, economic and scientific progress.

Chapter 2 argued that the government has two very distinct roles in promoting interdisciplinary research: bottom-up facilitation and a top-down focus on societal challenges. Mixing these two roles increases the complexity of policy instruments, squeezes the scope for bottom-up cooperation and leads to frustration among researchers. These two roles therefore need to be more clearly distinguished from each other. That will also help remove obstacles to interdisciplinary collaboration.

AWTI puts forward four recommendations to turn this into practice, which incorporate the 'aces' referred to in section 2.3. The first two recommendations – the combination of which is crucial – lead to clarification and strengthening of the two government roles. Recommendations 3 and 4 are more general in nature.

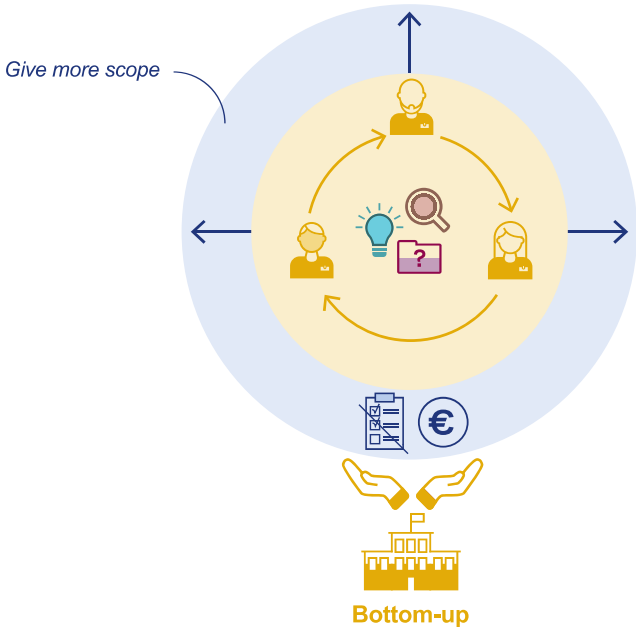
- Facilitate bottom-up interdisciplinarity more wholeheartedly, and apply less conditions.
- Make clearer choices to concentrate research in a limited number of research platforms for achieving societal transitions,
- Promote interdisciplinary research through higher education.
- Connect and apply knowledge on interdisciplinarity more effectively in policy and practice.

3.1 Recommendation 1: Facilitate bottom-up collaboration more wholeheartedly

AWTI advises the Ministry of Education, Culture and Science to fund bottom-up interdisciplinary research with confidence and with fewer conditions attached. In putting

forward this recommendation, the Council is seeking to provide an impulse for the first government role, namely bottom-up promotion of interdisciplinarity.

Recommendation 1
Facilitate and fund bottom-up interdisciplinarity more wholeheartedly and apply fewer conditions



What will it achieve?

More scope for bold, groundbreaking, unbound basic research will promote bottom-up interdisciplinarity, thereby strengthening the scientific base in the Netherlands.[52] Sending out an unambiguous signal will offer clarity to researchers: the government is facilitating interdisciplinarity with confidence.[53] This is also likely to lead to an attractive climate for top scientists wishing to work in interdisciplinary teams.[54] Finally, lowering the barriers to

52. This outcome is in line with the findings of scientific research on interdisciplinary cooperation (Uzzi et al., 2013; Van Hal, 2021) and an analysis of ERC data https://erc.europa.eu/news/impact-erc-research-confirmed2020.
53. Cf. Crone (2021).
54. See also other publications on the attractiveness of countries for scientists (Wuchty, Jones & Uzzi, 2007; KNAW, 2018).

the bottom-up inclusion of ‘non-scientists’ will also provide a boost for interdisciplinary cooperation through the involvement of civil-society parties.

Elaboration 1: A new programme

The space for bold, groundbreaking unbound research has shrunk in recent years for various reasons. This is despite the fact that this type of research, which is often interdisciplinary, has in the past delivered paradigm-shifting insights with great societal impact,[55] and will continue to be very necessary in the future. The Dutch Ministry of Education, Culture and Science is the perfect department to facilitate this type of research more wholeheartedly, with confidence and conviction, and to defend its importance.

It is therefore time for a new, open competitive programme, focusing on scientific excellence and interdisciplinary collaboration in small teams.[56] This is precisely the kind of research which more often than not leads to interdisciplinary breakthroughs; however, there is currently no such programme in the Netherlands.[57] Proposals should be assessed boldly for their potential to deliver major breakthroughs (see also Recommendation 4). Model this programme on the example of the ERC Synergy Grants (see Boxes ‘Examples of bottom-up interdisciplinarity’ on page 20 and ‘Good practice: ERC Synergy Grants assessment process’ on page 42) and given substantial funding. The Dutch Research Council’s Talent Programme would seem to be a logical home for such a programme.

Elaboration 2: Lower the barriers for ‘non-scientists’

In addition, more opportunities need to be created for bottom-up inclusion of non-scientists in the various types of research. This requires amendment of the funding conditions operated by the Dutch Research Council, for example by removing the co-funding requirement for stakeholders who do not stand to benefit financially from the research but who do help to achieve societal impact.[58] The value of transdisciplinary research and citizen science is after all undisputed, but the involvement of these parties is currently often self-funded, presenting a major obstacle to participation. An example is the collaboration between artists and scientists.[59] Consideration should therefore be given to

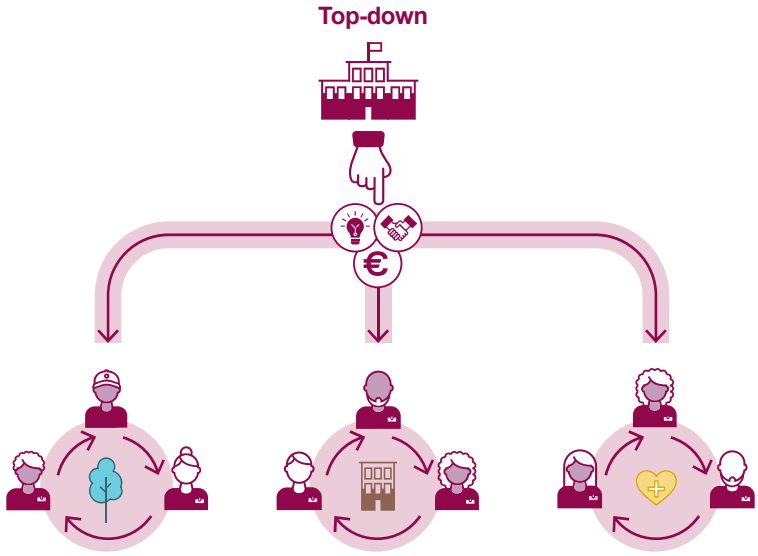
55. Examples of such research include the discovery of DNA, the emergence of climate science or the development of Covid-19 vaccines (Flexner, 1939; Debackere et al., 2020)
56. Small teams have a strong track record in achieving scientific breakthroughs (Lee, Walsh & Wang, 2015; Wu, Wang & Evans, 2019).
57. The Gravitation programme is focused on large consortia, with limited opportunities for interdisciplinary collaboration.
58. Unlike companies, they do not earn back their investment. Examples include patient associations, citizen collectives or artists.
59. See e.g. https://ias.uva.nl/research/artscience/artscience.html and https://waag.org/nl/tags/art-science

making funding available for the research carried out by these parties, as is also (more) usual in the European framework programmes.[60]

3.2 Recommendation 2: Make clearer choices for top-down collaboration

AWTI advises the government to make clear choices, For example by concentrating top-down interdisciplinary cooperation in a limited number of research platforms, each with a specific priority for societal transitions, and by removing tax obstacles. This recommendation will bolster the second government role: top-down promotion of interdisciplinarity.

Recommendation 2
Make clearer choices to concentrate top-down collaboration in research platforms for societal transitions



60. Those programmes also draw less of a distinction between the types of party eligible for funding.

What will it achieve?

Implementing this recommendation is likely to lead to an acceleration of transitions and an amelioration of societal problems. This acceleration is needed, and interdisciplinary cooperation is crucial to achieving it.[61] This will give researchers a place where they can contribute directly to solutions for societal challenges, a key driver for a large group of researchers who do not currently always receive the recognition they deserve. If this group are able to carry out research via these platforms, they will be less dependent on other instruments (subsidies and grants, programmes), reducing the pressure on those schemes. They will also be less dependent on university groups, which are often organised on disciplinary lines.

Elaboration 1: Create a number of large-scale collaborative research platforms

The experience that has been gained in recent years with mission-driven research policy is a positive development.[62] The problems facing the Netherlands today, however, demand a more robust response spanning several years. AWTI advises the government to create a limited number of large, collaborative research platforms, each focusing on a key societal challenge that will face the Netherlands in the coming decade.[63] This should begin during the present government term, with two or three such platforms, for example focusing on priorities from the Coalition Agreement. Taking responsibility for these collaborative research platforms will require substantive knowledge on the part of the government about the challenges. For the creation and embedding of this knowledge, the Council refers to its report 'State of knowledge'.[64] Organising the research platforms will also require knowledge about interdisciplinarity; see Recommendation 4 below.

The research on which the platforms focus may not deliver short-term financial wins,[65] but the results could help society advance. It is important that collaboration takes place across scientific disciplines (arts, sciences, social sciences) and along the whole

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61. See AWTI report 'Strengthen the role of STI in societal transitions' (AWTI, 2020).
62. For example, the change of course in the Top Sectors policy means more emphasis is placed on societal missions and thus creates scope for research and innovation with the potential to deliver both economic and societal benefits.Societal challenges do not always deliver gains in the short term, but interdisciplinary research is still needed. Under the 'Thematic Programming' programme strand, the National Research Agenda offers government ministries the opportunity to fund research based on societal themes. In most cases, these are still relatively small calls. For more information, see the description by the Rathenau Instituut (2021).
63. This recommendation is inspired by the theory and practice of collaborative platforms. As stated in chapter 2, organisational structures and/or physical facilities which are not organised along disciplinary lines remove obstacles to interdisciplinary collaboration.
64. See AWTI reports 'State of knowledge' (AWTI, 2021) and 'Strengthen the role of science, technology and innovation in societal transitions.' (AWTI, 2020).
65. And is not covered by the Top Sectors policy. Or as Janssen, Hekkert & Frenken put it: "Not every societal problem can be solved through commercial innovation" (2019). Examples include challenges such as climate change, housing or poverty.

knowledge chain (universities, universities of applied sciences, applied research institutes and practical research).[66] The government can choose the platforms (and their priorities) based on an overarching vision for the future.[67] It would then make sense to align with the knowledge and innovation priorities in Horizon Europe.[68] The investment must be substantial if it is to achieve the necessary scale and acceleration of transitions (more than 100 million euros per priority area).[69] The time horizon must be sufficiently long. The responsible sectoral departments should contribute to the funding and also play a substantive and coordinating role for the platforms. For issues such as energy and climate, for example, responsibility may be expected to lie with the Ministry of Economic Affairs and Climate Policy and the Ministry of Infrastructure and Water Management, respectively. When it comes to inequality (e.g. of opportunities), responsibility may be expected to lie with the Ministry of Education, Culture and Science and the Ministry of Social Affairs and Employment, respectively. And for issues relating to security, we may expect the Ministry of Justice and Security and the Ministry of Defence to take responsibility. In many cases, this will also require cooperation between policy domains within and between ministries. Existing knowledge and methods in relation to interdisciplinarity can form an increasing part of this relationship, e.g. 'key enabling methodologies' (see Box 'Knowledge, methods and skills in relation to interdisciplinarity' on page 44). Recommendation 4 looks at this in more detail.

The research platforms must not be isolated entities, but must be linked to existing knowledge institutes and infrastructures.[70] AWTI recommends drawing inspiration for the platforms from another recent form of interdisciplinarity, 'convergence spaces'.[71] These spaces bring together disciplines, actors and technologies, often based around a specific societal challenge or a particular technology (see Box 'Convergence spaces' on page 35). The Council proposes a broader interpretation of these spaces so that they can also be used to address societal challenges without a direct need for technology.

66. See the call by Dirks (2021) for the 'reconciliation' of the two cultures (sciences and humanities)
67. See AWTI report 'Strengthen the role of science, technology and innovation in societal transitions.'
68. Such as the European missions: 1. Adaptation to Climate Change, 2. Conquering Cancer, 3. Restore our Ocean and Waters by 2030. 4. 100 Climate-Neutral and Smart Cities by 2030. 5. Caring for Soil is Caring for Life.
69. Meirmans et al. (Meirmans *et al.*, 2019) compare the distribution of research funding in nine countries and, based on this, put forward a number of constructive suggestions in line with this elaboration of the recommendation.
70. This will enable them to grow and develop and they will be complementary to the national research institutes (Royal Netherlands Academy of Arts and Sciences (KNAW) and the Dutch Research Council (NWO)) and the Large-scale Research Infrastructure.
71. See Stokols (2020) for a conceptualisation of the term 'convergence'.

Convergence spaces

The OECD[72] defines convergence spaces as places which bring together different elements: disciplines, actors and technologies. These spaces:

- synthesise traditional disciplines by attracting and training scientific staff from a range of disciplines;
- bring together different actors who can work together around resources (financial physical) and new developments;
- foster the convergence of technologies.

The OECD has analysed 32 international convergence spaces. The lesson drawn from this analysis is that success depends on the degree to which knowledge from different disciplines or non-scientific actors is integrated. If technology conversion is added to this, the spaces can generate the strong synergies that are needed for innovation.

Convergence spaces are emerging in several places in the Netherlands. Delft University of Technology (TU Delft), Erasmus Medical Centre and Erasmus University have for example set up a 'convergence square' at Erasmus Medical Centre,[73] where scientists and other partners work together on the theme 'Health and Technology'. The facility will serve as a physical meeting place for a period of two to three years. It will be equipped to make it easy to connect digitally with other convergence squares, such as those being created at Erasmus University and Delft University of Technology.

Elaboration 2: Remove tax obstacles to collaboration

Whilst knowledge institutes are increasingly collaborating, AWTI believes there are unnecessary fiscal obstacles. The Council advises the Ministry of Education, Culture and Science, possibly together with the Ministry of Finance, to investigate whether these obstacles could be removed. Researchers must be able to involve colleagues in current research projects who are employed at a different knowledge institute. That makes it simpler to bring together specific complementary expertise. When researchers seek to do this now, they have to pay VAT on the services provided by 'external' researchers. This does not apply for collaboration between employees within one and the same knowledge institute.

72. Winickoff et al. (2021)
73. See the press release on the opening at https://convergence.nl/opening-of-the-first-convergence-square/

3.3 Recommendation 3: Promote interdisciplinarity through higher education

AWTI recommends that interdisciplinary collaboration be promoted in education programmes, and specifically where that collaboration extends across faculties and organisations or in fields where major opportunities and challenges are likely. Interdisciplinarity in education is an important breeding ground for interdisciplinary collaboration in research, from which the disciplines of the future emerge. Interdisciplinary education programmes expose students to knowledge from several disciplines, who can then apply this combined knowledge, as well as acquiring skills in interdisciplinary collaboration. Higher education establishments generally have the autonomy to launch their own interdisciplinary programmes and convergence education, but the Ministry could offer support for bottom-up initiatives and also reduce the relative disadvantage of interdisciplinary education in the assessment of programmes

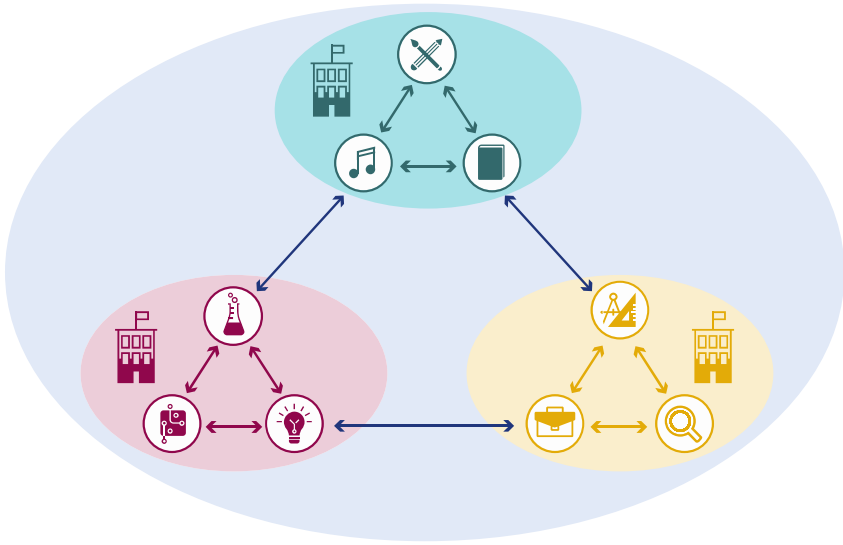
What will it achieve?

A strong disciplinary basis is essential for some forms of interdisciplinary research collaboration.[74] However, interdisciplinary teaching in higher education is an important stimulus for interdisciplinary research.[75] It equips new knowledge workers better to address complex scientific and societal challenges in the future. To do this, education establishments, in addition to disciplinary and interdisciplinary education, also need to develop convergence education:[76] programmes which combine at least two disciplines.[77]

74. This is argued among others in the report by the Young Academy on interdisciplinary education (Brink et al., 2018).
75. This also emerges from the analysis of obstacles and incentives for interdisciplinary research; see Appendix 3.
76. Monodisciplinary and interdisciplinary education can lead to different educational profiles. Michels (2019) describes the succession of educational profiles, such as a 'T-shaped profile' (an expanded monodisciplinary basis). A more recent phenomenon is the 'pi-shaped profile', featuring broadened dual disciplinary education, also referred to as convergence education. Examples of such programmes include medical humanities, digital humanities (see https://www.umcutrecht.nl/nieuws/umc-utrecht-universiteit-starten-nieuwe-master), the introduction of clinical subjects in biotechnology and the introduction of data science in medical training.
77. It is encouraging to note that universities that are regarded as having a technical focus are also beginning to feature in rankings for teaching in the arts and humanities; see https://www.timeshighereducation.com/news/arts-and-humanities-subject-rankings-2022-results-announced. This does not mean that all universities have to begin offering this kind of education; on the contrary, distinct profiles are desirable, and collaboration between education institutes makes interdisciplinary teaching possible. The Council therefore applauds the fact that education establishments are seeking out interdisciplinary collaboration through collaboration with other institutes (AWTI, 2019).

Finally, interdisciplinary education creates opportunities for collaboration within and between education institutes and for the creation of distinctive profiles.[78]

Recommendation 3
Promote interdisciplinarity through higher education



Elaboration 1: Support the development of programmes which promote interdisciplinarity

The Strategic Agenda for Higher Education and Research, published by the Ministry of Education, Culture and Science, emphasises the importance of the appropriate skills for interdisciplinary research. The Agenda explores what this means for education. This reveals that more and more education programmes are devoting attention to these skills, for example by using society as a learning environment, employing hybrid learning environments and engaging in interdisciplinary teaching. Interdisciplinarity is promoted through contacts between students on different programmes and in different disciplines. This is reflected in programmes such as Future Planet Studies (University of Amsterdam)

78. See also the report 'Shaking up the system'. (AWTI, 2019)

and Liberal Arts and Sciences (Utrecht University). AWTI welcomes these developments and recommends that they be supported.

Education establishments are leading this trend, but developing new initiatives demands serious up-front investment. That is difficult to achieve, especially for interfaculty (or even inter-organisational) programmes – hence the recommendation by AWTI that the Ministry of Education, Culture and Science provide financial support and assistance to help education establishments remove practical obstacles (such as differences in timetabling and course credits) to institutes working together.[79]

Elaboration 2: Reduce the relative disadvantages for interdisciplinary education in the assessment of programmes

The Council notes that interdisciplinary teaching and convergence of disciplines is taking place in education programmes. A point to bear in mind here is that there are relatively more obstacles to setting up interdisciplinary programmes than for monodisciplinary programmes. This could make it unnecessarily difficult to set up progressive interdisciplinary programmes. The system contains sufficient checks and balances, which largely appear to operate as intended, and which are important in ensuring the quality of programmes. Despite this, the Council advises the responsible bodies to explore how two relative disadvantages can be addressed, namely disciplinary quality assessment and labour market need.

As regards the former, the Accreditation Organisation of the Netherlands and Flanders (NVAO) assesses the quality of new programmes, which if approved are given accreditation. Interdisciplinary programmes are regularly accredited, but new interdisciplinary or convergent programmes suffer the disadvantage that quality is generally assessed on a disciplinary basis. A programme at the interface of arts and technology cannot be assessed exclusively on the basis of the quality standards applying for one of the two disciplines, whereas the assessors do often have a background in one discipline.

Second, the Efficiency of Higher Education Assessment Committee (CDHO) tests the efficiency of new programmes, with approval leading to funding. Public funds are limited, and these assessments are therefore crucial. Here too, interdisciplinary programmes are regularly approved, but innovative interdisciplinary programmes are at a considerable disadvantage. One of the three criteria used in judging the efficiency of programmes is labour market need. In principle, the rules allow for that need to be interpreted in various

79. See Brink et al. (2018).

ways, but in practice labour market surveys are the main tool used.[80] The Council would point out here that scientific and societal changes take place very rapidly and that assessments of future need are hedged in with great uncertainty. There is a risk of overestimating the labour market need for programmes that are not highly innovative, and underestimating the need for very innovative programmes.

Dutch and international examples of interdisciplinary higher education programmes

Bachelor of Arts and Sciences in Interdisciplinary Problems & Methods (London University)

The London Interdisciplinary School (LIS, London University) offers a Bachelor of Arts and Sciences degree in Interdisciplinary Problems & Methods. A Master's degree programme is currently being developed. The Bachelor's degree is the first undergraduate programme of its kind in the United Kingdom. It focuses on specific problems, learning about concepts and theories from different disciplines and gaining experience with a range of interdisciplinary qualitative and quantitative research methods. Coaching also plays a central role in the degree programme. Members of the LIS faculty support small groups of students by creating space for 'synthesis and metacognition', in other words space for students to try out new ideas and make mistakes. These weekly sessions help students to reinforce their knowledge and establish connections between disciplines.

Transdisciplinary education in higher professional education

Dutch universities of applied sciences make wide use of educational formats[81] in which students carry out research in practice with or receive education from companies, local authorities and other civil-society organisations. One example is BlueCity, where students from Rotterdam University of Applied Sciences work alongside start-ups on issues surrounding the circular economy. Another example of the combined work experience places offered by HAN University of Applied Sciences, Radboud University and Rijn IJssel Regional Training Centre. Here, students from a range of disciplines work together with professionals from the region on urban themes in the social domain.[82]

80. This is also one of the criteria applied in the extended test developed by TNO Research as used by NVAO.
81. Known by all kinds of different names, such as Community Service Learning, Community Engaged Learning, Integrated Learning and Society Based Education.
82. For more examples, see Appelman & Verbeek (2021).

Interdisciplinary Bachelor's degrees (UvA)

The Institute for Interdisciplinary Studies (IIS) at the University of Amsterdam offers several interdisciplinary bachelor's programmes, for example combining arts with social sciences (Bèta-gamma), Future Planet Studies, and Brain and Cognitive Sciences. IIS also offers interdisciplinary subjects as options. The Institute is also heavily engaged in educational development, on which it shares knowledge, publications and best practices.

Bachelor's programmes 'Umwelt Problem Lösen' (ETH Zürich)

ETH Zürich offers a Bachelor's programme 'Umwelt Problem Lösen' ('Solving Environmental Problems') I, II and III as part of (USYSTdLAb) in the Environmental Systems Science department. This is a 'transdisciplinary lab' which carries out both research and teaching in the field of climate research. Students of these subjects work on a single project focusing on a climate problem of their choice. At the heart of this initiative is good collaboration in research, a combination of design and systems thinking and the involvement of civil-society parties, who are brought in for the identification of topics, research goals and knowledge-sharing. The students learn to combine theoretical and practical knowledge and to reflect from the start of their research on practicable measures for tackling climate problems.[83]

3.4 Recommendation 4: Connect and apply knowledge about interdisciplinarity more effectively

AWTI recommends that the knowledge around interdisciplinary research in a broad sense be linked and used more effectively at government ministries, the Dutch Research Council and also at knowledge institutes themselves. An important condition for this is that the knowledge possessed by the different organisations be developed further and connected better, and that the link between theory and practice be improved.

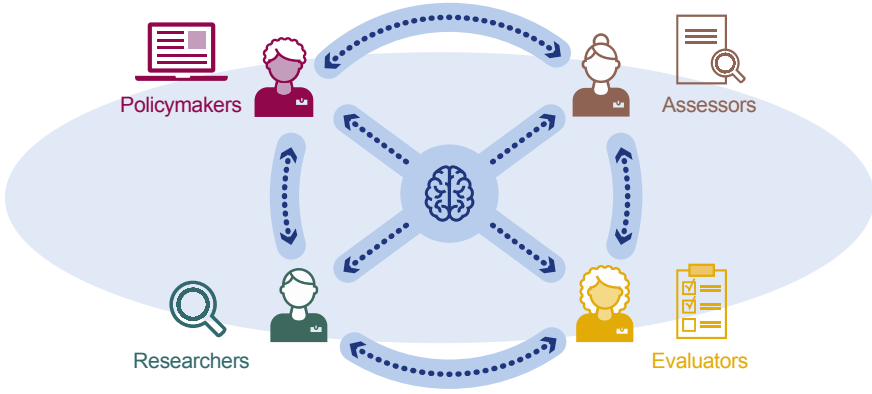
What will it achieve?

Implementing this recommendation will mean that policymakers, implementing bodies and researchers will be bringing to bear the appropriate knowledge in relation to interdisciplinarity. It will contribute to better[84] assessment of research proposals and

83. www.upltdlab.ethz.ch/
84. What counts as 'better' is thus fundamentally linked to what type of interdisciplinary collaboration is envisaged.

better implementation of those proposals. It will also help keep Dutch science policy at the forefront and could serve as an example for research policy elsewhere, for example in the European Union. This will mean that Dutch research institutes and researchers are well prepared for the European Union's science, technology and innovation policy.[85]

Recommendation 4
Connect and use knowledge about interdisciplinarity more ef fectively



Elaboration 1: Make better use of existing knowledge about interdisciplinarity

Interdisciplinary research is and will remain a central plank of a well-functioning research system, and up-to-date knowledge about it in terms of both policy and practice is consequently indispensable. The recommendation is therefore to develop the knowledge around interdisciplinarity in a broad sense at the Ministry of Education, Culture and Science, the Dutch Research Council, other government ministries and knowledge institutes themselves. Among other things, this means knowledge about the skills needed to lead, carry out and assess interdisciplinary research projects (see Box 'Good practice:

85. AWTI will publish a report on this later in the year.

ERC Synergy Grants assessment process' below), knowledge about team science[86], or knowledge about transdisciplinary research methods.[87]

For researchers, knowledge and skills such as these often fall outside the traditional academic assessment process. Organising and carrying out interdisciplinary research effectively calls for integration skills, for example.[88]

Knowledge about interdisciplinarity is not only important for developing and carrying out interdisciplinary research projects, but also for policy development by knowledge institutes, government ministries and implementing bodies. A research proposal that integrates two disciplines often receives only a moderate rating from those disciplines, whereas the integration could potentially be groundbreaking. Assessors and the organisations which facilitate the assessment need knowledge about interdisciplinarity as well as the appropriate skills to deliver a proper assessment.[89] It is therefore important that the organisations involved have a culture in which this kind of knowledge is valued and where it is the norm to keep up to date with the latest insights about interdisciplinary research.[90]

Good practice: ERC Synergy Grants assessment process

The assessment process for ERC Synergy Grants is geared to the interdisciplinary nature of the submitted proposals. The process allows maximum scope for adjustments along the way. Discussions with stakeholders revealed that the composition of the assessment committees is crucial; they must be the very best people, who are able to recognise groundbreaking research. Failure to ensure this runs the risk that 'tomorrow's research' will be assessed by 'yesterday's scientists'.

The assessment process for Synergy Grants consists of the following steps:

- An applicant submits a proposal.
- A panel of 87 assessors can be called upon. Four or five experts from the total group assess the proposal. Where necessary, they seek additional input from experts drawn from permanent ERC panels. Roughly 50 percent of applications are rejected at this stage.

86. A rich research tradition has arisen in recent years around team science (Stokols, Misra, et al., 2008; Heinze et al., 2009; National Research Council, 2014; Brown, Deletic & Wong, 2015; Ledford, 2015; Fortunato et al., 2018; Schot & Steinmueller, 2018).
87. https://www.uu.nl/en/research/transdisciplinary-field-guide/methods-resources
88. See e.g. https://www.4tu.nl/cee/innovation/project/13243/integration
89. It is striking that this generally means that interdisciplinary research proposals are less likely to receive funding. At the ERC, by contrast, interdisciplinary proposals are actually more likely to be approved. There is thus genuinely something to be learned here.
90. In a general sense, see also the report 'State of knowledge' (AWTI, 2021).

- The 87 assessors are then dynamically assigned to five panels, based on their expertise and on the fields to which the remaining applications relate. The panels are grouped around the assessors from step 2 and are large, comprising 16 to 18 people. Out of the 87 assessors, 11 subsequently meet in Brussels to discuss the applications and interview the applicants. These delegated panel members are themselves generalists and draw on the necessary specialist input from external experts who are not members of the panels, also known as 'remote referees'. The grant applicants and their principal researchers must present their proposal and themselves, and the panel representatives assess how the members of a group get on with each other. This is a very important aspect of the assessment process, because the team will be working together for several years. In this step, the interview panels can be adjusted again depending on the expertise that is needed to conduct the interviews.[91]

Elaboration 2:Connect knowledge between organisations and between theory and practice

Knowledge about interdisciplinarity is increasing nationally and internationally (see Box 'Knowledge, methods and skills in relation to interdisciplinarity' on page 44), but is still very fragmented and has no clear focal point in the Netherlands. To remain at the forefront in interdisciplinary research, it is important that this knowledge finds its way to researchers, assessors, evaluators and policymakers who are involved with interdisciplinary research.

There are already some developments in this regard, such as the knowledge platform for interdisciplinary research set up by the Dutch Research Council (NWO). It is for the Ministry of Education, Culture and Science to monitor whether the connecting and sharing of knowledge is adequate. AWTI believes that linking and sharing knowledge must embrace interdisciplinarity in a broad sense, with a view to helping policymakers, assessors and funders to recognise the different forms of interdisciplinarity. A good network ('community of practice') brings together all stakeholders: policy advisers and researchers at knowledge institutes, policymakers and research funder assessors,[92] as well as researchers and lecturers who are involved with interdisciplinary collaboration in

91. Analysis of research funded by ERC shows that a proposal with a high degree of interdisciplinary research attracts a higher assessment score. That is striking, because a study of national research funders shows that interdisciplinary proposals actually receive a lower assessment score (Bromham, Dinnage & Hua, 2016). It would seem that the ERC assessment process is promoting interdisciplinary breakthroughs. See https://erc.europa.eu/news/impact-erc-research-confirmed2020
92. As well as the Dutch Research Council (NWO) and the Netherlands Organisation for Health Research and Development (ZonMW), these also include charity funding, etc.

practice. This network ensures the dissemination of knowledge about different forms of interdisciplinarity from places where it exists to places where it is needed.

Knowledge, methods and skills in relation to interdisciplinarity

Interdisciplinary research requires specific knowledge, methods and skills, for example knowledge about the different forms of interdisciplinarity and how it can be adequately assessed and implemented. Different methods are also applied for the different forms of interdisciplinary research. Interdisciplinary research also demands different skills from researchers than disciplinary research. A few examples are given below.

SHAPE-ID (European Union)

The SHAPE-ID project is a coordination and support programme under Horizon 2020.[93] The purpose of this project is to gain insights and collect best practices regarding interdisciplinary research and supporting it. SHAPE-ID offers a toolkit for different parties involved in interdisciplinary research: policymakers, research funders, knowledge institutes, researchers and research partners. This toolkit contains a series of 'guided pathways' to help and support, based on these roles or on the research goals. Other elements include case studies in various forms (reports, videos, cooperation tools, guides, tips, FAQ and a list of scientific and other publications about interdisciplinary research.

Key Enabling Methodologies (CLICKNL)

CLICKNL (the knowledge and innovation network of the Dutch Top Sector 'Creatieve Industrie ('Creative Industry') lists eight Key Enabling Methodology (KEM) categories – methodologies and tools grouped together for addressing different transition issues. They lend themselves perfectly to interdisciplinary research.[94] The eight KEMs are: Vision and imagination; Participation and co-creation; Behaviour and empowerment; Experimental Environments; Value Creation and upscaling; Institutional change; System change; and Monitoring and effect measurement. Different KEMs can be used for different forms of interdisciplinary research. For example, the methods in the category 'participation and co-creation' can help with transdisciplinary research in consortia. These methods make it possible to go through participation processes

93. Accessible at https://www.shapeidtoolkit.eu/
94. See https://www.clicknl.nl/de-creatieve-industrie/key-enabling-methodologies/. The KEMs are available in several locations, including at https://kems.clicknl.nl/

systematically, to help engage stakeholders and to analyse and understand issues in context.

Scientific research on interdisciplinary research

The Centre for Science and Technology Studies (CWTS) at Leiden University carries out research on scientific research and on the relationship between science, technology, innovation and society.[95]

Innovation Map (4TU Federation)

The 4TU Federation (a partnership of four Dutch universities of technology) has developed an 'Innovation Map'. It contains information on educational innovation projects at the 4TU universities, including access to tools, research results and best practices.[96] One of the innovation projects is 'Innovation'. This project focuses on various forms of integration: integration of knowledge, skills and attitude; of different disciplines in an education programme; and of knowledge at basic and applied level The Map also includes projects focusing on transdisciplinary learning and working in interdisciplinary groups.

Rathenau Instituut

The Rathenau Instituut carries out research on the impact of science, technology and innovation on society. It publishes regular research reports on transdisciplinary research, open science and citizen science.

95. For a list of all publications, see https://www.cwts.nl/research/publications
96. Accessible at https://www.4tu.nl/cee/innovation/

Bijlagen

Appendix 1 Creation of this report

AWTI used four methods in the exploratory study carried out in preparation for this report: literature reviews (both scientific and 'grey' literature), an external international study, interviews and a number of meetings.

Analyses

The first analysis focused on the conceptualisation of 'interdisciplinarity'. Interdisciplinarity is a broad term, which encompasses a range of other terms such as multidisciplinary and transdisciplinary and also touches on other concepts (such as citizen science). The study consisted in defining these terms based on the literature. The outcome is briefly summarised in the Box 'Definition of interdisciplinarity' on page 11, which also contains a number of references to further reading. An analysis was also performed of trends and developments which influence interdisciplinary research. To do this, insights from interviews and Council discussions were supplemented with information from the literature. A. summary was also compiled of all policy instruments impinging on interdisciplinary research, as well as an analysis of their influence on interdisciplinarity. Policy documents, parliamentary papers and websites of various organisations were used for this. This summary was submitted for verification to staff at the Ministry of Education, Culture and Science. The policy summary was used to underpin chapters 2 and 3. Finally, an analysis was performed of the barriers and incentives for interdisciplinary research. In this analysis, interviews with researchers were combined with a review of scientific literature. The results are set out in Appendix 3. The results were used as a basis for chapter 2 as well as input for chapter 3 (Recommendations).

External research

AWTI also commissioned external research on policy pertaining to interdisciplinary collaboration in science and higher education in other countries. This research was carried out by Technopolis Group, whose report can be found on the AWTI website (www.awti.nl). The core of the research consists of case studies focusing on policy to promote interdisciplinary research in Germany, Finland, the United Kingdom and the European Union. The countries were chosen based on a number of criteria, such as presence of special options for funding interdisciplinary research, general investments in research and development, and participation in Horizon 2020. Documentary evidence and interviews in the countries concerned were used for this. The analysis took place at three levels: national government, public (implementing) organisations and knowledge institutes. The research concluded with options for the Netherlands. The present report regularly draws on and refers to this rich study.

Interviews

Two types of interviews were conducted for this report. First, a total of 15 exploratory interviews were held with staff of the Ministry of Education, Culture and Science, the Ministry of Economic Affairs and Climate Policy, the Dutch Research Council (NWO), Universities of the Netherlands (UNL, formerly the Association of Universities in the Netherlands, VSNU), the Royal Netherlands Academy for Arts and Sciences (KNAW), the Centre for Science and Technology Studies (CWTS), UNESCO, the Accreditation Organisation of the Netherlands and Flanders (NVAO), the Efficiency of Higher Education Assessment Committee (CDHO) and the Rathenau Instituut. Among other things, these interviews explored what interdisciplinary research is, what trends and developments are relevant and what the government and/or other organisations could do to improve the facilitation of interdisciplinary research. These insights formed the context for this report and provided input for the various analyses or testing of insights.

A further 11 interviews were held with scientists about their experiences with interdisciplinary research and education. An attempt was made to obtain the widest possible spread across the various knowledge institutes and different career phases. These interviews homed in on the barriers and incentives experienced by researchers in their own research, interdisciplinary or otherwise. These interviews were used as input for Chapter 2 and in Appendix 3.

Meetings

Finally, several meetings were organised and attended during the preparation of this report. First, a joint workshop was organised with the Danish counterpart of AWTI, Danmarks Forsknings- og Innovationspolitiske Råd (DFIR). Both Councils focused on the subject of interdisciplinary research during this workshop. Two meetings were also organised with a focus group comprising staff from the Dutch Ministry of Education, Culture and Science. Subsequently, on 16 October 2021, an expert meeting was held in Utrecht with experts from the fields of science and policy (Ministry of Education, Culture and Science and Ministry of Economic Affairs and Climate Policy). This meeting discussed the main points of the analysis and looked ahead to the report and the possible recommendations. Finally, several meetings were attended in the preparation of this report: a meeting in the context of the ‘Digital Society’ programme organised by VSNU/UNL, the annual conference of the Taskforce for Applied Research SIA, the Conference on the Social Impact of Science & Technology in the Netherlands and Flanders; the Knowledge Festival organised by the Ministry of Education, Culture and Science; Dutch Design Week; and the conference of the European Forum for Studies of Policies for Research and Innovation 2021.

Appendix 2 List of university research institutes

The Rathenau Instituut observed in 2012 that university organisations in the Netherlands are becoming increasingly complex.[97] This is due to the emergence of (interfaculty) research institutes in which several disciplines work together in a specific field (for example in the form of 'hubs' or 'focus areas') and the creation of (top) research schools and graduate schools. In 2012, research in many universities was concentrated in research institutes and schools; see Table 1. The Rathenau Instituut concluded that the traditional division of universities into faculties was slowly changing to one based more on teaching and research institutes and schools.

For this report, AWTI updated the Rathenau Instituut table (Table 2). A key addition to the mix are University Colleges (UCs). (Interdisciplinary) faculty institutes were also studied to gain a deeper insight into university structures. That insight supported the analyses in chapter 2 of this report. The results are summarised in the final column of Table 2.

Our conclusion is that the trend observed by the Rathenau Instituut has continued. An increasingly dynamic system is evolving alongside the traditional university structures. As an example, Eindhoven University of Technology (TU Eindhoven) has added a number of strategic themes to the existing research structure, while Wageningen University & Research (WUR) now only carries out research within themes, and no longer within schools. Some universities have introduced a clear change of strategy even though the formal structure has changed little. Utrecht University, for example, has set up a vertical research structure alongside the existing faculties and research institutes, made up of strategic themes, hubs and focus areas.

Table 1 Organisational structures at universities (by Rathenau Instituut 2012)

University	Education	Research
Erasmus University Rotterdam	Faculties or Schools (7, incl. Medicine)	Research schools (interfaculty and intrafaculty) Research institutes (interfaculty and intrafaculty)
Radboud University Nijmegen	Faculties (7, incl. Medical sciences)	Institutes and centres (intrafaculty)
University of Groningen	Faculties (9, incl. Medical sciences)	Research schools (intrafaculty) Research institutes (intrafaculty)
Delft University of Technology	Faculties (8)	Research schools (interfaculty) Research institutes (interfaculty)

97. By Chiong Meza (2012).

		'Delft Research Initiatives' (interfaculty)
Eindhoven University of Technology	Faculties (9)	Faculty research programmes
Leiden University	Faculties (7, incl. Medicine)	Institutes and centres (intrafaculty)
Maastricht University	Faculties (6, incl. Medicine)	Research institutes (intrafaculty) and graduate school for PhD students
University of Twente	Faculties (6)	Research institutes (interfaculty)
Utrecht University	Faculties (7, incl. Medicine)	Departments (intrafaculty)
University of Amsterdam	Faculties (7, incl. Medicine)	Research institutes
Tilburg University	'Schools' (5)	Research institutes (interfaculty and intrafaculty) Research centres
VU University Amsterdam	Faculties (13, incl. Medicine)	Research groups
Wageningen University & Research	One faculty is divided into five departments	Research schools and graduate school for PhD students

Table 2 Organisational structures at universities (inventory by AWTI 2021)

University	Education	Research	Institutes
Erasmus University Rotterdam	Medical faculty + Schools (6) + UC (since 2013)	4 'areas' spread across schools	X* 'schools' and (faculty) institutes, 2 'special' intrafaculty institutes
Radboud University Nijmegen	Faculties (7 incl. medical)	15 institutes (see adjacent)	15 inter-faculty research institutes (of which 5 recognised by KNAW), two independent institutes
University of Groningen	Faculties (9 incl. medical) + UC (since 2014) + Campus (incl. UC since 2018)	Centres and institutes within and between faculties	15 interfaculty research institutes, X faculty research institutes
Delft University of Technology	Faculties (8)	Faculties + disciplines (just under 40)	16 university-wide, interdisciplinary institutes (Delft Institutes)
Eindhoven University of Technology	Schools (2) under which faculties fall (7)	Faculties (7) and research in strategic areas (3)	3 university-wide research institutes, plus X faculty research institutes

Leiden University	Faculties (7 incl. medical) + UC (since 2010)	Five broad clusters	31 faculty institutes, 3 intrafaculty institutes
Maastricht University	Faculties and schools (6 incl. medical) + UC (since 2002)	Via faculties and institutes, but also affiliated in vertical strategic themes	53 faculty research institutes
Twente University	Faculties (5) + UC (since 2013)	Faculties and research institutes (see adjacent)	3 university-wide research institutes
Utrecht University	Faculties (7 incl. medical) + 2 UC (since 2004 and 1997)	Via faculties and institutes, but also affiliated in vertical strategic themes, hubs and focus areas	X faculty research institutes
University of Amsterdam	Faculties (7) + UC (together with VU, since 2009)	Via faculties and institutes + 9 interfaculty hubs	26 faculty institutes
Tilburg University	Faculties or schools (5) + UC (since 2016, prior to that LAS)	Graduate schools of faculties and many institutes (see adjacent)	37 faculty and interfaculty research institutes
VU University Amsterdam	Faculties (9) + UC (together with UvA, since 2009)	4 multidisciplinary profile themes	20 interdisciplinary intrafaculty institutes
Wageningen University & Research	Via Wageningen University, under which 5 faculties fall	Via Wageningen Research, under which 6 faculties fall	9 interfaculty research institutes

* *X means that the total number of institutes could not be determined from the website*

Appendix 3 Factors which inhibit or promote interdisciplinary research

This Appendix summarises a number of inhibiting and enabling factors for interdisciplinary research This is based on a literature review and interviews with researchers in the Netherlands.

Factors associated with the nature of interdisciplinary research

A number of inhibiting and enabling factors for interdisciplinary research are inherent in the nature of scientific research involving several disciplines.[98]

Table 3 Factors associated with the nature of interdisciplinary research

Factor	Notes	Sources
Large conceptual and methodological differences (inhibiting)	These differences between disciplines and domains are difficult or impossible to bridge.	(Institute of Medicine, 2004; MacLeod, 2018)
Lack of transparency and language or cultural differences (inhibiting)	Another discipline can be confusing, hard to understand and hard to grasp for an outsider. The language, journals, networks, practices, etc. are all different.	(Mauser *et al.*, 2013; MacLeod, 2018)
Quality standards and conflicts over epistemological values (inhibiting).	Disciplines and research fields apply specific values and standards regarding what constitutes 'correct' knowledge and which methods should be used to develop knowledge. Reconciling these differences is difficult.	(MacLeod, 2018)
Lack of structure to solve problems (inhibiting).	The 'environment' in which interdisciplinary research takes place often lacks structure because it is often innovative, searching and exploratory.	(MacLeod, 2018)
The inherent complexity of nature and society (inhibiting).	Searching for answers to complex questions about how the world functions requires an interdisciplinary approach.	(Institute of Medicine, 2004)

98. These have also been referred to as the problems 'from which we must learn' (Douglas, 2021).

From the interviews

Virtually all interviewees said that interdisciplinary research demands a lot of time, space and energy. Researchers therefore need to have sufficient opportunity and reason to abandon the familiar and 'easier' path of disciplinary research.

Factors associated with personal characteristics

A number of inhibiting and enabling factors for interdisciplinary research are related to personal characteristics of the researchers themselves.

Table 4 Factors associated with personal characteristics

Factor	Notes	Source
Personal goals, values and expectations (inhibiting or enabling)	Researchers who are driven by a desire to solve a societal problem are more likely to consider interdisciplinary research. Attitudes towards interdisciplinary collaboration also play a role.	(Carayol & Thi, 2005; Stokols, Misra, *et al.*, 2008; Van Rijnsoever & Hessels, 2011; Wagner *et al.*, 2011)
Experience, skills and role models (inhibiting or enabling)	Positive/negative previous experience with interdisciplinary collaboration.	(Carayol & Thi, 2005; Van Rijnsoever & Hessels, 2011)
Tolerance of problems associated with interdisciplinary collaboration (enabling)	Willingness to accept the difficult aspects of interdisciplinarity (see Table 3, above) is important. This is about tolerance of tensions, inefficiencies and disappointments.	(Stokols, Misra, *et al.*, 2008; National Research Council, 2014)

From the interviews

Most interviewees cited the desire to solve societal problems as the biggest motivation for interdisciplinary research. A desire for innovation in science is also a strong motivating factor. It helps if researchers are relatively tolerant of the inherent challenges of interdisciplinarity.

Interviewees also mentioned that having their own interdisciplinary network can help a researcher engage in interdisciplinary collaboration, and that individual researchers need to have both courage and perseverance in making the move to interdisciplinary cooperation.

A few interviewees added that researchers at the start of their careers often find it more natural to engage in interdisciplinary research, for example because they have learned about this during their studies or because they have not yet become extensively

'socialised' within a particular discipline. Conversely, they felt that 'established' researchers should be given more freedom to step beyond disciplinary boundaries.

Factors associated with the group in which interdisciplinary research takes place

A number of inhibiting and enabling factors for interdisciplinary collaboration are situated at the level of groups.

Table 5 Factors associated with the group in which interdisciplinary research takes place

Factor	Notes	Source
Shared mission and common questions (enabling)	Researchers with varied knowledge and backgrounds work together more effectively on a shared mission or common issues.	(Brown, Deletic & Wong, 2015; Schot & Steinmueller, 2018)
Transaction costs (inhibiting)	Interdisciplinarity demands more time and capacity. Adjustments are often needed along the way because projects are more uncertain and more complex.	(Fiore, 2008)
Team dynamic (enabling)	Teams with a high level of cohesion, diversity and flexibility are better able to carry out interdisciplinary research.	(Stokols, Misra, *et al.*, 2008; Heinze *et al.*, 2009; National Research Council, 2014; Brown, Deletic & Wong, 2015)
Team science (enabling)	Team science means that different roles are recognised and are effectively assigned within a team.	(Stokols, Hall, *et al.*, 2008; Fortunato *et al.*, 2018)
Group think (inhibiting)	Groups which have worked together for a long time and become isolated are susceptible to confirming each other's existing ideas. They are less open to interdisciplinary research questions.	(Stokols, Hall, *et al.*, 2008)

From the interviews

The transaction costs of interdisciplinary research were mentioned as an inhibiting factor in many of the interviews. On the other hand, mutual respect and appreciation, and creating an environment in which group members are able to make mistakes were mentioned as motivating factors.

In relation to the team dynamic, one interviewee observed that it is often small interdisciplinary teams that deliver the most innovative and disruptive research results. Consortia that are too big have little flexibility.

Factors associated with organisation, technology and physical environment

A number of inhibiting and enabling factors for interdisciplinary research are related to the organisation(s) (research institutes) in which interdisciplinary research is carried out, the physical environment within which research is performed and the technologies that are available.

Table 6 Factors associated with organisation, technology and physical environment

Factor	Notes	Source
Organisational structures (inhibiting or enabling)	Traditional divisions of faculties and departments are often inhibiting factors. Interdisciplinary centres, hubs and themes, by contrast, are enabling factors.	(Institute of Medicine, 2004; Stokols, Misra, *et al.*, 2008; Heinze *et al.*, 2009; Mauser *et al.*, 2013; National Research Council, 2014)
Organisational culture (enabling)	Non-hierarchical culture, staff rotation, internal incentives for interdisciplinary collaboration, diversity of viewpoints and the extent to which information, ideas and appreciation are shared are enabling factors for interdisciplinarity.	(Stokols, Misra, *et al.*, 2008; Heinze *et al.*, 2009; National Research Council, 2014; MacLeod, 2018)
Physical proximity (enabling)	Physical proximity helps interdisciplinary cooperation. This may be achieved on a small scale by creating comfortable and inspiring spaces where different groups can meet. But it is also possible on a local or regional scale, on campuses or in regional clusters of ecosystems.	(Stokols, Misra, *et al.*, 2008; Sá, 2008; Heinze *et al.*, 2009; Wagner *et al.*, 2011; National Research Council, 2014; MacLeod, 2018)
Cooperation outside the organisation (enabling)	Working together with companies, civil-society actors and applied research institutes contributes to more/better interdisciplinary collaboration. The questions and problems that are relevant outside the research institutes are more likely to be found at the interfaces between or outside research disciplines.	(Institute of Medicine, 2004; Carayol & Thi, 2005; van Rijnsoever & Hessels, 2011; Schot & Steinmueller, 2018)
Technological factors (enabling)	There are technical systems and new technologies which help interdisciplinary collaboration. These include effective communications technology and secure digital platforms which facilitate collaboration. Innovative technological infrastructure, technical	(Institute of Medicine, 2004; Stokols, Misra, *et al.*, 2008; Keestra, 2013; National Research Council, 2014)

	facilities, supercomputers, generative or key technologies or large databases are also supportive.	
Discipline-based education/training programmes (inhibiting)	Many programmes are based on a single discipline. This leads to discipline-specific funding via students and to graduates trained within a single discipline.	(Sá, 2008; MacLeod, 2018)
The right/adequate training profiles (enabling)	As well as monodisciplinary training programmes, there are also interdisciplinary programmes in which additional courses are offered alongside a main discipline in order to broaden the programme. There are also 'convergence programmes', where two disciplines are integrated in the teaching. This leads to different profiles, such as T-shaped' and 'pi-shaped'. These students become accustomed to interacting with other disciplines during their training. That promotes interdisciplinary collaboration in research.	(Brown, Deletic & Wong, 2015; Brink *et al.*, 2018)
Interdisciplinary courses (enabling)	Offering interdisciplinary courses requires cooperation between lecturers from different research disciplines. This is an enabling factor for interdisciplinary research.	(National Research Council, 2014; Brink *et al.*, 2018)

From the interviews

A high proportion of interviewees explicitly mentioned the fact that faculties are structured in disciplinary 'columns' (silos) as a constraining factor for interdisciplinary research. One interviewee felt this was less of a problem at universities of applied sciences than at (academic) universities, because the boundaries between disciplines are less static in the former. Conversely, (interdisciplinary) institutes are seen as enabling factors for interdisciplinary research.

The importance of a physical location as an enabling factor for interdisciplinarity was mentioned frequently. Shared buildings, rooms and/or research equipment can facilitate interdisciplinary collaboration.

Most interviewees regarded a strong disciplinary basis as a condition for such interdisciplinary collaboration. Opinions differed on the usefulness of interdisciplinary training programmes, but generally the preference was for disciplinary (bachelor's) programmes with the ability to pursue interdisciplinary subsidiary subjects or Master's degrees.

Factors associated with the institutional context of the research

The final category of factors are institutional in nature; they are social and political factors and aspects such as funding.

Table 7 Factors associated with the institutional context of the research

Factor	Notes	Source
Journals, rankings, indices and peer review (inhibiting)	The smaller the field, the easier it is to define quality standards. Consequently, most journals are discipline-specific. Rankings also favour journals with a narrower set of topics. In order to be able to publish, submitters must meet the language and topic requirements set by journals. The referees of those journals often come from the disciplinary school and are less able to assess the value of interdisciplinary research.	(Rafols *et al.*, 2012; Mauser *et al.*, 2013; MacLeod, 2018)
Academic reward systems (inhibiting)	Academic career pathways are largely discipline-specific. Rewards (fairs, rankings and promotions) are largely based on disciplinary output. Conversely, interdisciplinary research is associated with higher risks and a greater time investment	(Institute of Medicine, 2004; Carayol & Thi, 2005; Yang, 2011; Mauser *et al.*, 2013; Fortunato *et al.*, 2018; MacLeod, 2018)
Competitive funding (inhibiting)	The way competitive research funding is organised often means that interdisciplinary research is less likely to succeed or is undervalued.	(Stokols, Misra, *et al.*, 2008; Heinze *et al.*, 2009; National Research Council, 2014; Bromham, Dinnage & Hua, 2016; Scholten, Van Drooge & Diederen, 2018; Commissie-Rinnooy Kan, 2020; Scholten *et al.*, 2021)
Individual prizes and fares (inhibiting)	Many research prizes and fairs are aimed at individual scientists. Whilst this can in principle also include interdisciplinary research, this does not facilitate the creation of interdisciplinary teams.	(Heinze *et al.*, 2009)
Discipline-based assessment committees (inhibiting)	A great deal of research funding is discipline-based. This funding is distributed through discipline-specific committees of research funders or disciplinary faculties of institutes.	(Institute of Medicine, 2004; Evers *et al.*, 2015; Bromham, Dinnage & Hua, 2016; Fortunato *et*

		al., 2018; Commissie-Rinnooy Kan, 2020)
High pressure on the scientific system (inhibiting)	The scientific world is characterised by strong (international) competition, heavy teaching obligations in some fields of science, the need for research to be socially relevant and a high administrative burden. But interdisciplinary collaboration demands more time and effort to get it off the ground and the risk of failure is greater. The high pressure on the research system is therefore seen as a relatively inhibiting factor for interdisciplinarity when compared with disciplinary research.	(Stokols, Misra, *et al.*, 2008; Fortunato *et al.*, 2018)
Research evaluation (inhibiting)	Research evaluation is traditionally organised along disciplinary lines. Interdisciplinary research is undervalued or even excluded from this system.	(Institute of Medicine, 2004; Rafols *et al.*, 2012; Smit & Hessels, 2021)
Specific interdisciplinary incentives (enabling)	Specific programmes, funding and evaluation for interdisciplinary research can contribute to interdisciplinarity.	(Brown, Deletic & Wong, 2015)

From the interviews

The disciplinary path as the route to a 'successful' academic career was cited by many interviewees as a key inhibiting factor for interdisciplinary science. Ultimately, assessment is still mainly carried out using indicators such as the h-index. Recent developments in relation to recognition and evaluation are regularly cited as a possible change in this situation.

Many interviewees felt that basing the allocation of direct government funding on student numbers is an inhibiting factor for interdisciplinary research. One interviewee stated that 'powerful' disciplines such as medicine and economics, which receive the bulk of the funding, often see less value in interdisciplinary research. The faculty structure is also reinforced by the allocation of funds, making it difficult to organise interdisciplinary collaboration across faculties.

Almost all interviewees stressed that the assessment of interdisciplinary research proposals is notoriously problematic. Researchers often assess interdisciplinary proposals primarily from the basis of their own disciplines, rather than viewing the proposal in the round. On the other hand, assessment committees are sometimes too broadly constituted, meaning that specific disciplinary elements cannot be properly valued. Finding the right people for the assessment of interdisciplinary research is crucial,

and one interviewee suggested that too little use is made of assessors from outside the Netherlands.

Many interviewees also mentioned the fact that the Dutch Research Council (NWO) is organised into four areas as an obstacle to interdisciplinary collaboration (although it has been reorganised from nine component parts). Broad interdisciplinary collaboration (spanning the boundaries between the arts, exact sciences, social sciences or medical sciences) often does not fit neatly into one of the NWO 'pigeon-holes' (despite these being relatively broad). In line with this, the inhibiting effect of the current competitive funding system was broadly supported in the interviews. The National Research Agenda (NWA) is regarded by some as an enabling factor and by others as an inhibiting factor.

Appendix 4 Interviewees

Below is a list of the individuals who were interviewed for this report or who attended the expert meeting.

Bas van Bavel	Utrecht University
Koen Beumer	Utrecht University
Wiebe Bijker	Maastricht University
Marike Bontenbal	UNESCO
Wouter Boon	Utrecht University
Jeanet Bruil	Dutch Research Council (NWO)
Nikki Brand	Delft University of Technology
Anno Bunnik	Universities of the Netherlands
Eveline Crone	Leiden University
Wim van den Doel	Leiden University
Jacob Eerbeek	Ministry of Economic Affairs and Climate Policy
Andrea Evers	Leiden University
Anne Flierman	Accreditation Organisation of the Netherlands and Flanders (NVAO)
Stan Gielen	National Open Science Programme
Rianne Hermans	Ministry of Education Culture and Science
Laurens Hessels	Rathenau Instituut
Jarno Hoekman	Utrecht University
Wendy Hoogeboom	Ministry of Education Culture and Science
Martijn Janmaat	Ministry of Economic Affairs and Climate Policy
Lisa Janssen	Efficiency of Higher Education Assessment Committee (CDHO)
Janneke Kersten	Dutch Research Council (NWO)
Ilkay Kizyl	Ministry of Education Culture and Science
Yvonne Klerks	Ministry of Education Culture and Science
Peter Knorringa	Erasmus University Rotterdam
Jennifer Kockx	Delft University of Technology
Helianthe Kort	Eindhoven University of Technology and Utrecht University of Applied Sciences

► Marlies van Meent	Dutch Research Council (NWO)
► Barend van der Meulen	Twente University
► Herry Nijhuis	Dutch Research Council (NWO)
► Ismael Rafols	Leiden University
► Alexander Rinnooy Kan	University of Amsterdam
► Wim van Saarloos	Leiden University
► Peter Sloot	University of Amsterdam
► Appie Sluijs	Utrecht University
► Bas Steendam	Ministry of Economic Affairs and Climate Policy
► Peter Steenhuis	Ministry of Education Culture and Science
► Robbin te Velde	Dialogic Innovatie en Interactie
► Martijn Verwegen	Universities of the Netherlands
► Bram de Vos	Wageningen University and Research
► Ib Waterreus	Ministry of Education Culture and Science
► Ton Wilthagen	Tilburg University

In addition to these interviewees from the Netherlands, an external research agency carried out a study of policy on interdisciplinary research outside the Netherlands. Experts from 13 organisations outside the Netherlands were interviewed for this.[99]

99. See Menenti et al. (2021).

Appendix 5 References

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