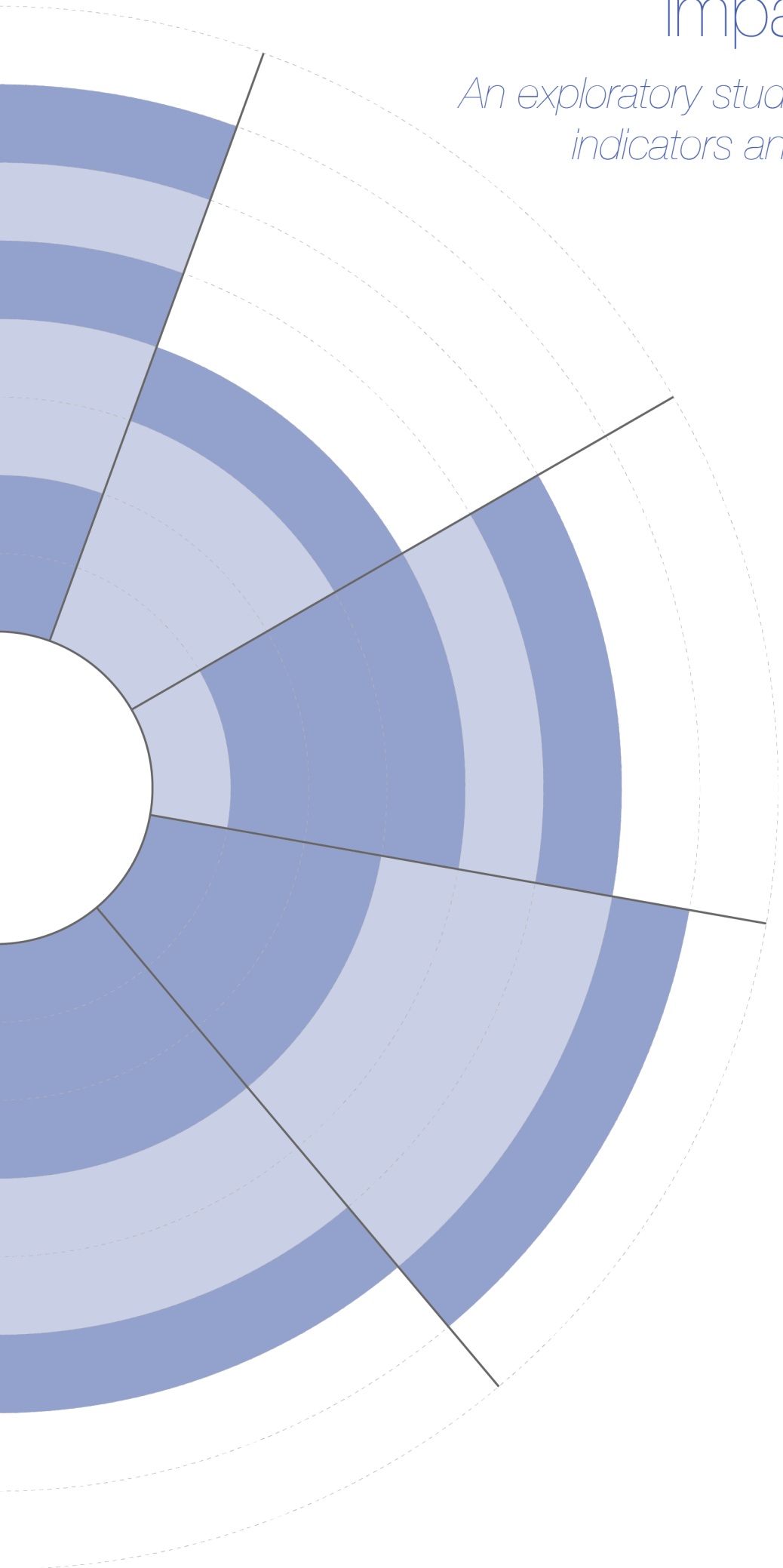
Impact mapping

An exploratory study into interpretations, indicators and enablers of impact

Rik Brouwer



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This thesis is the product of a Double Degree in the master programme Communication Design for Innovation and Life Science & Technology. Due to confidentiality, the study performed for Life Science & Technology is not included in this thesis. Therefore, a brief description is given:

"This study focuses on laboratory evolution of S. cerevisiae under anaerobic conditions. Hereto, evolution experiments in small-scale bioreactors were performed to increase the growth rate of these cultures and reduce the lag phase. Furthermore, whole genome sequences were analysed for possible mutations and single colony isolates were made, resulting in 18 S. cerevisiae strains. Additionally, the membrane composition of some of the acquired strains was analysed and growth studies were performed to characterise the growth rate of these strains."

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Summary

Showing the impact of your research has gained attention by the rise of research evaluation frameworks that relate funding to the impact of research. Despite the rise of these evaluations, impact remains a complex concept as it lacks general consensus on what is defined as impact. Therefore, this exploratory study set out to discover the variety in interpretations of impact, possible indicators of impact and what enables impact generation. Based on this knowledge, a design proposal for a tool that maps impact is developed. This is done with the goal to help researchers to get more awareness of the impact of their research or themselves.

First a systematic literature review is conducted to explore the variety of interpretations of impact. Further analysis of these interpretations led to the development of guidelines for a general interpretation of impact, with the following general interpretation as a result '*Research impact is a direct or indirect influence of research outcomes*'. This analysis also gave insight in the areas where impact could be found, which were defined as: scientific, technological, economic, social, cultural, political, environmental, health and educational impact. Furthermore, various organisational levels were identified where impact could be found, namely: on an individual, local, regional, community, organisational, societal, national and international level. The systematic literature review also led to the identification of indicators of impact per area of impact.

Based on semi-structured interviews with academic staff members of the Department of Biotechnology, possible enablers for generating impact were identified. Aforementioned results were used to develop a design proposal for an impact mapping tool, which led to the creation of the Impact Radar, together with a workshop-like workflow. As part of the double degree between Life Science & Technology and Communication Design for Innovation the Impact Radar was used to map the impact of the thesis performed for Life Science & Technology.

The Impact Radar provides an overview of the impact of a project or person. After further development and testing, this tool could be used in research evaluation frameworks, to provide more clarity and transparency in the evaluation process.

1 Introduction

"Work it harder, make it better, do it faster, makes us stronger," the lyrics to the 2001 song Harder, Better, Faster, Stronger by the French duo Daft Punk, are more relevant today than ever. Society demands technological development of new tools, more applications and better infrastructure, but as quickly as possible. Answering to society's demand are institutes, academia and industry, trying to rapidly develop these new technologies. However, doing research costs money, and therefore demonstrating the value of your work, or impact of your work, is as important as the work itself.

Since there is only a limited amount of resources available to fund research some countries have started working with a framework for the selection of which research proposals to fund. The UK started using the Research Excellence Framework (REF) in 2014, which operates with a threefold purpose i) to provide accountability for public investment in research and produce evidence of the benefits of this investment, ii) to provide benchmarking information and establish reputational yardsticks, for use within the Higher Education sector and for public information, and iii) to inform the selective allocation of funding for research (UK Research and Innovation, n.d.). In Australia the Excellence in Research for Australia (ERA) is deployed, and mentions as a benefit of the system that it "allows research managers and investors to identify and reward excellence in research and opportunities for further development or investment and assures Australian taxpayers that their investment in research is well spent – facilitates strategic planning to further strengthen our research capabilities" (Australian Research Council, 2018). The Netherlands have developed a much broader initiative 'Evaluating Research in Context' (ERiC), which "aims at addressing both methodological questions with respect to new forms of evaluation and questions that regard the implementation of these methods into national or even international evaluation systems". This would lead to more comprehensive research evaluation that includes 'societal quality' and 'valorisation' based on the participation of stakeholders and various disciplines (Spaapen, Dijstelbloem, & Wamelink, 2007). All three mentioned frameworks, REF, ERA and ERiC, are assessment methods to determine the social relevance of science, determining the relevance of research by a case study-type analysis. These case studies often investigate the impact of specific research or scientists.

The need to show the impact of your research is of growing importance on an (inter)national level, but also on a local level. Here, at TU Delft, the topic 'research impact' is also gaining attention, especially since the new strategic framework was presented in 2017. The TU Delft Strategic Framework 2018-2024 titled *Impact for a better society* serves as a compass for decision making at all levels within the university. The changing role of universities in society, led to redefining the balance between the pursuit of world-class academic excellence and the expectations society has of TU Delft as a provider of life-enhancing education and expert solutions to societal problems, which gave rise to this framework (TU Delft, 2018b). The word 'impact' is key in this framework, as stated by TU Delft and encompasses the following in context of the strategy: "For us, impact can take many forms and can be found everywhere: from technological breakthroughs and practical applications to intangible cultural value and education; from political, social, economic, and environmental changes to the intrinsic value that society assigns to knowledge itself." Together with the strategic framework 2018-2014 the Global Engagement Framework is developed, which focusses on: Global Impact, Global Partnerships, Global Visibility and Global Community (TU Delft, 2018a). This document also mentions that it is TU Delfts ambition "to progress from being an internationally- respected, world-class national university to becoming a global leader in creating technology-based solutions to societal challenges". Although the document mentions the following: "As educating the next generation of responsible top-level engineers is the biggest impact that TU Delft has on society, a major objective of TU Delft is to continue to strive for education that is internationally acknowledged as world class and above all aligned with the professional challenges our students will face in the future", the majority of both the Global Engagement Framework and the Strategic Framework does not focus on education. As shown by the development of these frameworks, the management of TU

Delft moves the balance more towards TU Delft as a provider of life-enhancing education and expert solutions to societal problems.

Next to aforementioned (inter)national frameworks and organisational documents, that allow for the assessment of scientific research, metrics have been developed to measure the approximate impact of researchers based on their publication records. The h-index, for example, determines the maximum amount of papers, 'Z', with at least 'Z' citations (Hirsch, 2005). It is a simple numerical value that combines publication scores with citation scores but is insensitive to extreme outliers. From the h-index multiple other indexes have been defined, such as the g-index, the i10-index and the i20-index, but none of those have reached the same level of adoption among the scientific community as the h-index itself. However, the impact of a scientist or a study reaches further than 'just' publication scores and is therefore hard to quantify in numbers.

1.1 Problem

Impact is a complex topic, and despite the rise of metrics and frameworks it remains difficult to describe the impact of a certain study or person, since 'impact' is an all-purpose word (Dutch: 'containerbegrip'); there is no general consensus on what is defined as impact. Dictionaries, like Merriam-Webster ("Definition of Impact by Merriam-Webster," n.d.) define 'impact' as:

> *The force of impression of one thing on another : a significant or major effect*

And Oxford Dictionaries ("Definition of impact by Lexico," n.d.) define 'impact' as:

> *A marked effect or influence.*

Both the Merriam-Webster and the Oxford Dictionaries definitions are broad definitions of impact but give a good basis on which the interpretations for 'research impact' were built. Funding organizations and institutions focus especially on the impact of scientific research, and therefor academics focus on this as well. Conditions for when research has impact are often given, expanding on this 'basic' definition, and creating an organisation's own interpretation. The Higher Education Funding Council for England (2011) interprets 'research impact' in the REF, specifically outside of academia, as:

> *An effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia.*

They proceed by giving a list of what 'impact' includes, specifying 'an effect on, change or benefit to' for various 'what's', 'who's' and 'where's'. The former Research Council UK (RCUK), now UK Research and Innovation, (2014) excludes this final list, but does add that the impact should be demonstrable. They interpret 'research impact' as:

> *The demonstrable contribution that excellent research makes to society and the economy, of benefit to individuals, organisations and nations.*

This interpretation compared to the REF interpretation, adds the fact that the impact should be demonstrable, and also specifies organisational levels where the impact should be found. The London School of Economics (LSE) Public Policy Group (2011) interpret 'research impact' similar to the RCUK, and expand by adding what suffices as 'demonstrable'. LSE interprets 'research impact' as:

> *A recorded or otherwise auditable occasion of influence from academic research on another actor or organization. Impact is usually demonstrated by pointing to a record of the active consultation, consideration, citation, discussion, referencing or use of a piece of research.*

Others have worked with different interpretations of impact, like Schnitzler, Davies, Ross & Harris (2016). They derive an interpretation based on the REF interpretation, but also state that the impact should be recognised outside of academia, namely:

> *When the benefits from research are tangible, measurable and recognised outside of academia, research is said to have impact.*

While Kanefsky (2001) mentions the following interpretation, based on a document of the National Education Research Fund (NERF) from 2000, and states this is the least satisfactory interpretation of impact yet:

> *The influence or effect that educational research has on its audiences*

The NERF interpretation of impact does not specify that impact should be demonstrable, does not mention specific areas where impact is found, but does mention the vague organisational level 'audiences'.

As illustrated by the abovementioned interpretations, there is a range of what impact is considered to be, and how its interpretation has changed over the years. Since there is a range of interpretations of impact maintained in literature, it is very likely that different people uphold a different interpretation. As a consequence of such a variety of interpretations, a variety of goals could be set, and what one can consider as impact, could be insufficient for another, raising the question 'when is impact enough?'. Likewise, different parties could have different focus areas for impact, for example in a public-private collaborations, which in turn could lead to conflicts of interest. The central problem that arises here is the absence of consensus on the interpretation of impact, i.e. how can we expect people to work with the principle of 'research impact', when there is no consensus.

Linked to the absence of consensus, there is currently no overview of the areas where impact can be found. Having a clear overview of where a person or project has impact would have benefits on at least two accounts. Firstly, it would make it easier for researchers to communicate about that impact in funding requests or research evaluations. Secondly, such an overview could also be used as a guideline for the evaluation of funding requests or research evaluations, since there is no general method for this currently. Therefore, this study explores how a tool could help in creating an overview of the impact of researchers and/or their research projects.

Besides, the management of TU Delft has set out for TU Delft to become a provider of life-enhancing education and expert solutions to societal problems. However, they do not completely and clearly explain how to operationalize their goal. The framework *Impact for a better society* is a compass for decision making and although there is a broad interpretation given of 'impact' in context of TU Delft, they do not present how to generate impact.

1.2 Goal

The goal of this study is to help researchers at TU Delft get more awareness of the impact of their research. Although this study is performed in context of TU Delft, the results can be used outside of that context as well.

1.3 Research questions

Main research question:

MQ *How can a tool give scientists awareness of their impact?*

In order to answer this main research question, several sub questions are formulated:

RQ1 *What can or may impact entail based on literature and how can this lead to a general interpretation of 'impact'?*

RQ2 *What are possible indicators for impact by scientists?*

RQ3 *What are potential enablers and barriers for generating impact?*

RQ4 *What can a tool look like that maps the impact of scientists?*

1.4 Approach

This is an exploratory study, hereto this study will explore what impact entails and where it can be found (RQ1 & RQ2), and what could possibly enable or hamper impact according to scientists (RQ3). Finally, a design proposal for a tool to help scientists map their impact will be explored and tested (RQ4). This will form a foundation for further impact-related research which could lead to communication strategies for generating impact from research.

1.5 Methodological overview and report structure

In order to answer MQ a method inspired by the Double Diamond model (Design Council UK, 2005) is used. The original model uses consecutive phases of divergent and convergent thinking in the form of discover & define phases and develop & deliver phases. This form of divergent and convergent thinking is used by applying various methods, to answer RQ1 until RQ4 (Figure 1). Chapter 2 will describe a systematic literature review, with consequent concept coding, encoding and quantitative analysis in order to identify interpretations of 'impact', and answers RQ1 and RQ2. Next, Chapter 3 will describe the use of semi-structured interviews, with consequent concept coding and brief quantitative analysis, to identify possible enablers and barriers of impact, and answers RQ3. Following, in Chapter 4, the design proposal for a tool for impact mapping is described, together with a workshop testing the design, and answers RQ4. Chapters 2, 3 and 4 include detailed descriptions of methods used and discusses outcomes, followed by a conclusion to respective research questions, as a chapter conclusion. Chapter 4 is followed by a general discussion of research outcomes and recommendations for further research, Chapter 5, and a conclusion to MQ in Chapter 6. Finally, in Chapter 7 a synthesis is presented, which describes the use of the design proposal for an impact mapping tool, developed in Chapter 4, for mapping the impact of performed work for Life Science & Technology.

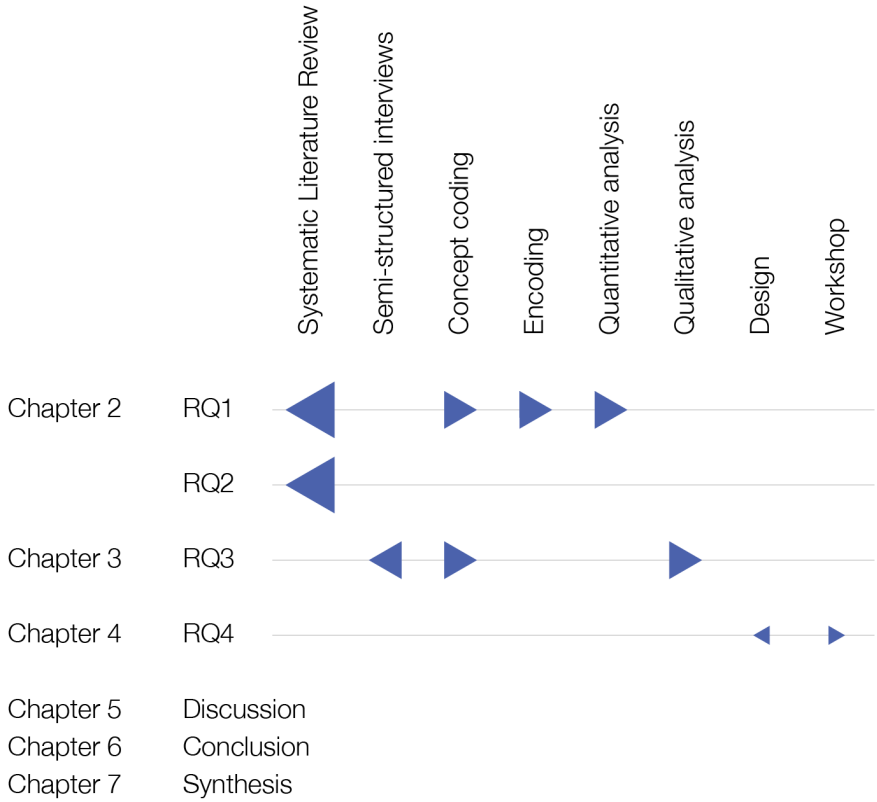

Figure 1. Report structure and methodological overview per research question. Left pointed triangles (◀) indicate phases of divergent thinking, right pointed triangles (▶) indicate phases of convergent thinking; size of symbols indicate relative importance of phase and method.

2 The identification of interpretations and indicators of impact

This chapter aims to answer the following research questions:

RQ1 *What can or may impact entail based on literature and how does this translate into a general interpretation of 'impact'?*

RQ2 *What are possible indicators for impact by scientists?*

In order to answer RQ1 a systematic literature review was performed, followed by concept-coding, encoding of interpretations of impact and further quantitative analysis. Detailed descriptions of the methodologies used are given in section 2.1. Based on these methods interpretations of impact were explored in literature, recommendations for a general interpretation of impact were made, and a selection of areas and scales of impact was made. These outcomes are presented and discussed in section 2.2. This is followed by an answer to RQ1 in the concluding section 2.3.

In order to answer research RQ2 the results of the aforementioned systematic literature review were concept-coded for indicators of impact (section 2.1), resulting in an overview of indicators of impact per area (section 2.2 and 2.3), previously determined when answering RQ1. A schematic overview of methods used and outcomes per research question is shown in Figure 2.

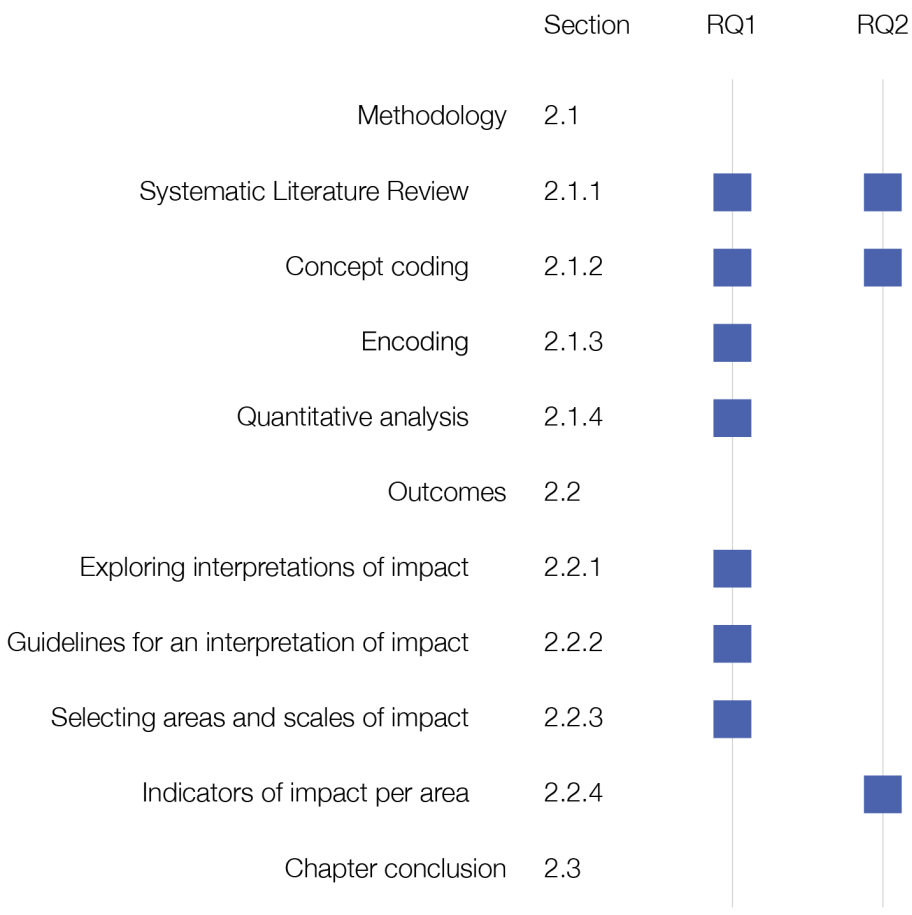

Figure 2. Schematic overview of the structure of Chapter 2, including methods used, outcomes and chapter conclusion.

2.1 Methodology

To explore the variety of interpretations of 'impact' in literature a systematic literature review (SLR) was performed. In addition to SLR, concept-coding was used to identify common themes in the variety of interpretations of 'impact', the areas and scales of impact, and indicators of impact. The presence of common themes in interpretations of 'impact' were encoded and quantitively analysed, in order to develop guidelines for a general interpretation of 'impact'. Furthermore, quantitative analysis was used to select areas and scales of impact, and all identified indicators of impact were grouped according to areas of impact. The combination of the interpretation of 'impact', the areas, scales and area-indicators give an overview of the scope of impact.

2.1.1 Systematic literature review

In order to explore and identify interpretations of 'impact' and possible areas and scales for impact, a systematic literature review (SLR) was performed, inspired by the PRISMA method (Moher, 2009). Based on an initial exploratory search, possible search terms for areas of impact were identified based on The Challenges of Impact Assessment of the European Science Foundation (2012), as: scientific, technologic, economic, social, political, environmental, health, cultural, education; academic was added to this query, since it is a frequent synonym of 'scientific', and is related to institutions were research is performed. It was expected that these search terms would yield a variety of interpretations of 'impact', i.e. different areas are likely to interpret impact dissimilar.

These areas, including wildcards[1], were searched for directly adjacent to, or with up to two words in between, 'impact' in combination with 'research', 'applied research', 'publication' or 'measurement'. Wildcards were included in the search to broaden the range of forms a word is used in a sentence. Additionally, 'publication' was included as it was expected it would yield literature discussing the impact of a publication, thus research impact; 'measurement' was included, as it was expected it would yield current methods to measure impact within aforementioned areas. Furthermore, a maximum distance of two words was used, since it was expected to be less likely for impact within a certain area to be discussed when the two were not in close proximity of each other.

An advanced search was performed, limited to titles of published articles, reviews and book chapters between 2009 and 2019 (performed August 1st) in the subject area 'Social Sciences' in the Scopus and Web of Science libraries (Text Box 1). The timeframe 2009-2019 was chosen to include relatively recent articles, reviews and books, since the subject of research impact was gaining attention during that period of time. Since research impact is most often approached from a social scientific perspective, it was chosen to limit the search to literature in the subject area 'Social Sciences'. Both Scopus and Web of Science libraries were chosen to investigate if these yielded different results, since this was suspected based on discussions with fellow students of the department of Science Education & Communication. It was chosen to limit the search to titles only, since 'impact' is a frequently used word when describing research and otherwise would yield close to 30,000 publications. This was considered to be too big for the scope of this thesis. Moreover, this would also limit the number of false-positives, i.e. publications using the word impact, but not in the context of 'research impact'.

[1] Wildcards in searches represent unknown characters and broaden the range of results when different forms of a word are used. Wildcards are represented by an asterisk.
Example: enzym* matches: enzyme, enzymes, enzymatic, enzymic

Scopus search query

TITLE(((scientific* OR technologic* OR economic* OR social* OR politic* OR environment* OR health OR cultur* OR education* OR academic*) W/2 (impact*) AND (research OR "applied research" OR publication* OR measurement*))) AND PUBYEAR > 2008 AND (LIMIT-TO (SUBJAREA,"SOCI")) AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"re") OR LIMIT-TO (DOCTYPE,"ch")) AND (LIMIT-TO (LANGUAGE,"English"))

Web of Science search query

((ti=((scientific* OR technologic* OR economic* OR social* OR politic* OR cultur* OR environment* OR health OR education* OR academic*) NEAR/2 (impact*) AND (research OR "applied research" OR publication* OR measurement*)))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article OR Book Chapter OR Review)

Indexes=SSCI Timespan=2009-2019

Text Box 1. Search queries for SLR in the Scopus and Web of Science libraries

The search results were further refined by selecting publications originating from 2009-2013 that received more than 5 citations; publications from 2013 onward were included without further refinement. It was chosen to exclude publications from 2009-2013 with less than 5 citations, since they were expected to contribute less to the field of research impact, as they were not cited in literature for at least 5 years. A schematic representation, adapted from the PRISMA method (Moher, 2009), of the flow of information through the different phases of the systematic review is shown in Figure 3.

Decisions for inclusion were made by the author of this thesis, unless mentioned otherwise. Records were first screened on basis of title and were excluded when the ‘impact’ discussed in the record was not related to impact originating from research. This was identified based on the phrasing of the title and the context, as far as this was possible, when this was unclear records were included for screening based on abstract. Secondly, records were screened on basis of abstract and were excluded if there was no clear mention of areas of impact or definition of ‘impact’. Studies focused on metrics, like altmetrics and bibliometrics, were also excluded, because this study focusses on identifying non-metric indicators of impact. Finally, full-text was assessed for the inclusion of records in this study. Records were included when there was a clear interpretation (or definition) of ‘impact’ mentioned; when areas of impact were mentioned; or when indicators for impact (in specific areas) were explicitly mentioned.

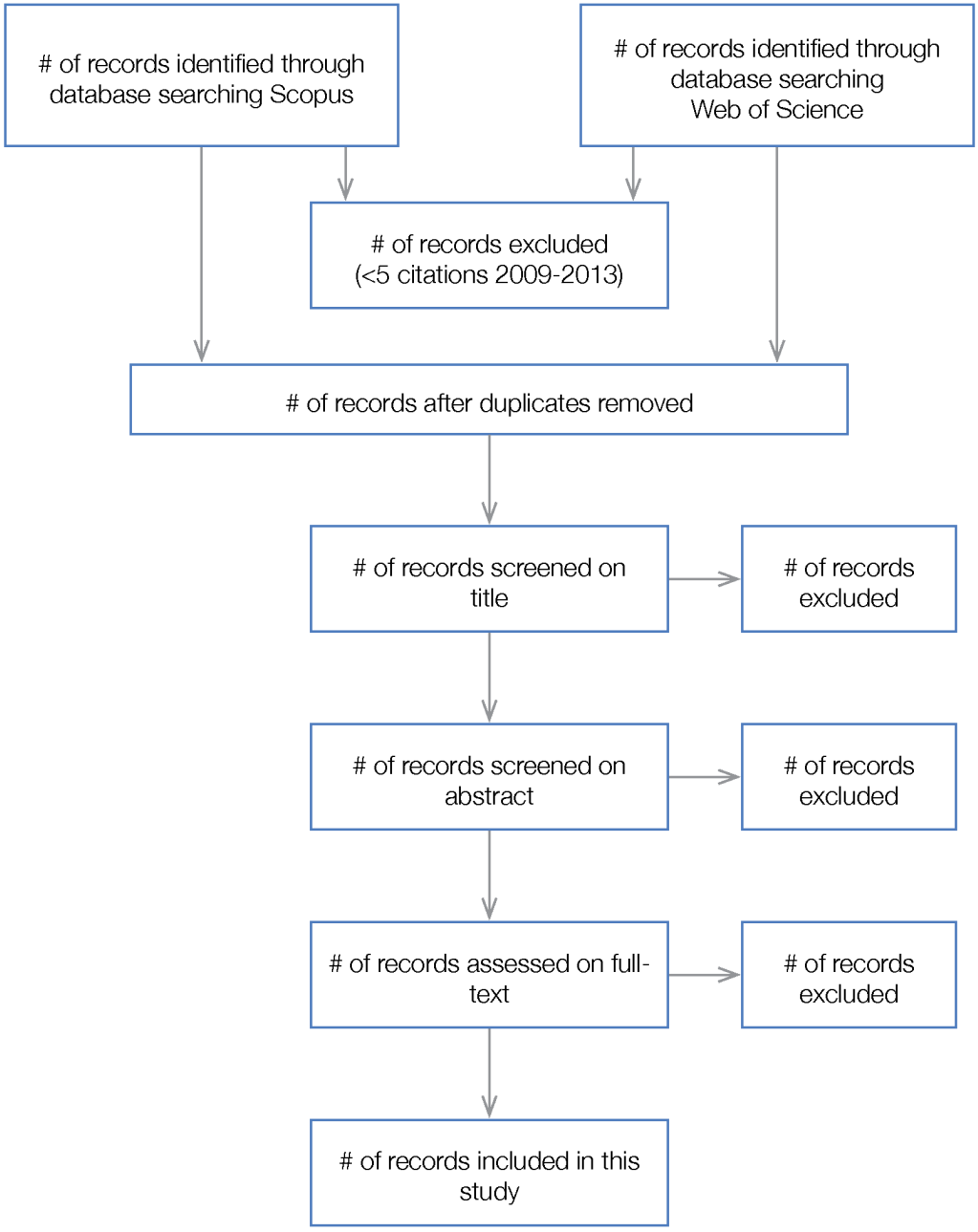

Figure 3. Flow chart of records for SLR inspired by the PRISMA flow chart *(Moher, 2009)*.

2.1.2 Concept coding

All included records were coded using NVivo 12, using the method of Concept coding (Saldana, 2015). Concepts used were: 'Interpretation' for all interpretations encountered in the records; 'Area' for all mentioned areas where impact is found; and 'Scale' for all mentioned levels and scales of impact; and 'Indicator' for all indicators of impact. Concepts 'Area' and 'Scale' were further divided in sub-concepts (Appendix I – Coding Tree Systematic Literature Review).

All coded indicators, related to an area of impact, encountered in the records included in this thesis, were combined and listed under their relevant area, after areas were selected according to quantitative analysis (section 2.1.4). This gives researchers more insights in where to place the impact of their research within the areas.

2.1.3 Encoding

While reading all text concept-coded as 'Interpretation' five themes were noticed by the author, which made up all interpretations of 'impact'. The themes noticed were:

- Bias in the word describing impact, further referred to as *Bias*
- Demonstrability of impact, further referred to as *Demonstrable*
- Area specification of where there is an impact, further referred to as *Area*
- Scale specification of where there is an impact, further referred to as *Scale*
- The type of impact either direct or indirect, further referred to as *Directness*

In order to investigate the commonality of these themes in the interpretations of 'impact', the author decided to identify and encode the presence of each of these five themes in the interpretations of 'impact'. Quantitative analysis, explained in section 2.1.4, was thought to give the most insight in the commonality of themes, therefore encoding the presence of themes was chosen as a method. Presence of *Bias*, *Demonstrable*, *Area* and *Scale* was encoded as '1' and the absence was encoded as '0', which resulted in a four-digit code. *Directness* was encoded separately, since it was often not meant explicitly, where direct impact was encoded as '1', and indirect impact was encoded as '0'. Further encoding criteria are presented below.

2.1.3.1 Bias

The first theme, *Bias*, is involved with the neutrality of the interpretation of 'impact' in the record. When a term with positive (or negative) connotations was used to describe impact, such as 'improve' or 'benefit', *Bias* was encoded as present (1). When neutral terms were used to describe impact, such as 'change' or 'influence', *Bias* was encoded as absent (0); in the presence of both biased and neutral terms, *bias* was encoded as absent (0).

2.1.3.2 Demonstrable

The second theme, *Demonstrable*, is involved with the demonstrability of impact of the given interpretation of 'impact' in the record. When it was specified, or implicated, that impact should be demonstrable, by words like 'demonstrable', 'citation', 'reference', 'patent' or 'measurable', *Demonstrable* was encoded as present (1). When the impact of research is demonstrable, it was assumed that this was also direct impact, e.g. a line between the research and impact can be drawn based on evidence. Therefore, when words like 'direct' were used, *Demonstrable* was also encoded as present (1).

When an interpretation did not specify that impact should demonstrable, by absence of previously mentioned words or the use of words like 'non-demonstrable', *Demonstrable* was encoded as absent (0). Similar to the inclusion of 'direct' as an indicator of *Demonstrable*, 'indirect' is used as an indicator for non-demonstrable, or the absence of *Demonstrable*, then *Demonstrable* was encoded as absent (0). In the presence of both demonstrable and non-demonstrable terms, *Demonstrable* was encoded as absent (0), since it is not obligatory to demonstrate the impact of research.

2.1.3.3 Area

The third theme, *Area*, is involved with the specification of an area/areas for impact in the given interpretation of 'impact' in the record. When an area/areas was/were mentioned in the interpretation, by words like 'social', 'economic' or 'beyond academia', *Area* was encoded as present (1). When the specification of an area for impact was absent, *Area* was encoded was absent (0).

2.1.3.4 Scale

The fourth theme, *Scale*, is involved with the specification of a scale/scales for impact in the given interpretation of 'impact' in the record. When a scale/scales was/were mentioned in the interpretation, by words like 'region', 'individual' or 'community', *Scale* was encoded as present (1). When the specification of a scale for impact was absent, *Scale* was encoded as absent (0).

2.1.3.5 Directness

The fifth theme, *Directness*, is involved with the inclusion of the type of impact, either direct or indirect, or both. When direct impact was explicitly mentioned, *Directness* was encoded as direct (1). When indirect impact was explicitly mentioned, *Directness* was encoded as indirect (0). When both direct and indirect impact were explicitly mentioned, *Directness* was encoded as indirect (1).

An example of the coding of the five themes is shown in Figure 4 for an interpretation of 'impact' found in Alla et al. (2017). For this interpretation of impact *Bias* is encoded as absent (0) since neutral terms are used to describe impact; *Demonstrable* is encoded as absent (0) since both demonstrable and non-demonstrable impact is included in the interpretation; *Area* is encoded as present (1), since areas of impact are mentioned; and *Scale* is encoded as present (1), since scales of impact are mentioned. *Directness* is encoded as direct (1), since both direct and indirect are explicitly mentioned in the interpretation. This results in the code '00111' for this interpretation of impact, in which each digit resembles one of the five aforementioned themes.

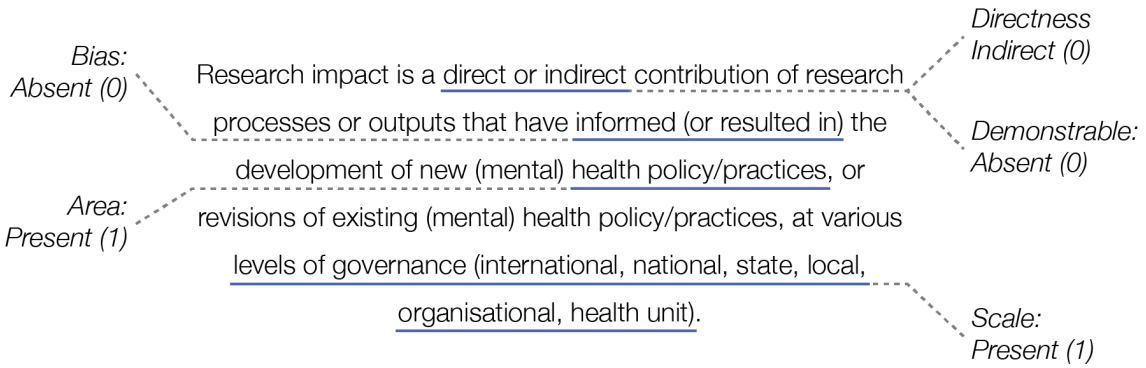

Figure 4. Example of encoding 'Bias', 'Demonstrable', 'Area' and 'Scale' in an interpretation of 'impact'. Bias is encoded as absent (0) since neutral terms are used to describe impact, demonstrable is encoded as absent (0) since both demonstrable and non-demonstrable impact is included in the interpretation, area is encoded as present (1), since areas of impact are mentioned, and scale is encoded as present (1), since scales of impact are mentioned. This results in the code 0011 for this interpretation of impact. Directness is encoded as direct (1), since both direct and indirect are mentioned.

2.1.4 Quantitative analysis

Simple quantitative analysis, by calculation of the percentage of occurrence per theme, gives insight in the commonalities of interpreting 'impact'. Furthermore, a correlation between *Directness* and *Demonstrable* is further investigated, based on the quantitative analysis by comparing the presence/absence of *Demonstrable* with the direct and indirect impact encoded in *Directness*. Based on this analysis recommendations are given for a general interpretation of 'impact'.

A simple quantitative analysis, by ranking of occurrence of all mentions of areas and scales concept-coded as 'Area' or 'Scale', was used to select the main areas and scales of impact.

2.2 Outcomes

2.2.1 Exploring interpretations of impact

The advanced search in the libraries of Web of Science and Scopus yielded 237 and 205 records respectively (Figure 5). After exclusion based on citation scores of papers published between 2009 and 2013, and removing duplicates, 294 records were submitted to screening on the basis of title. Of these 294 records, 91 were identified via both search engines, 128 unique records were identified using Web of Science and 66 unique records were identified via Scopus. This indicates that there is a difference between search engines, as was expected. Using both search engines will result in more hits, which could possibly lead to more useful information, therefor it is recommended to use both.

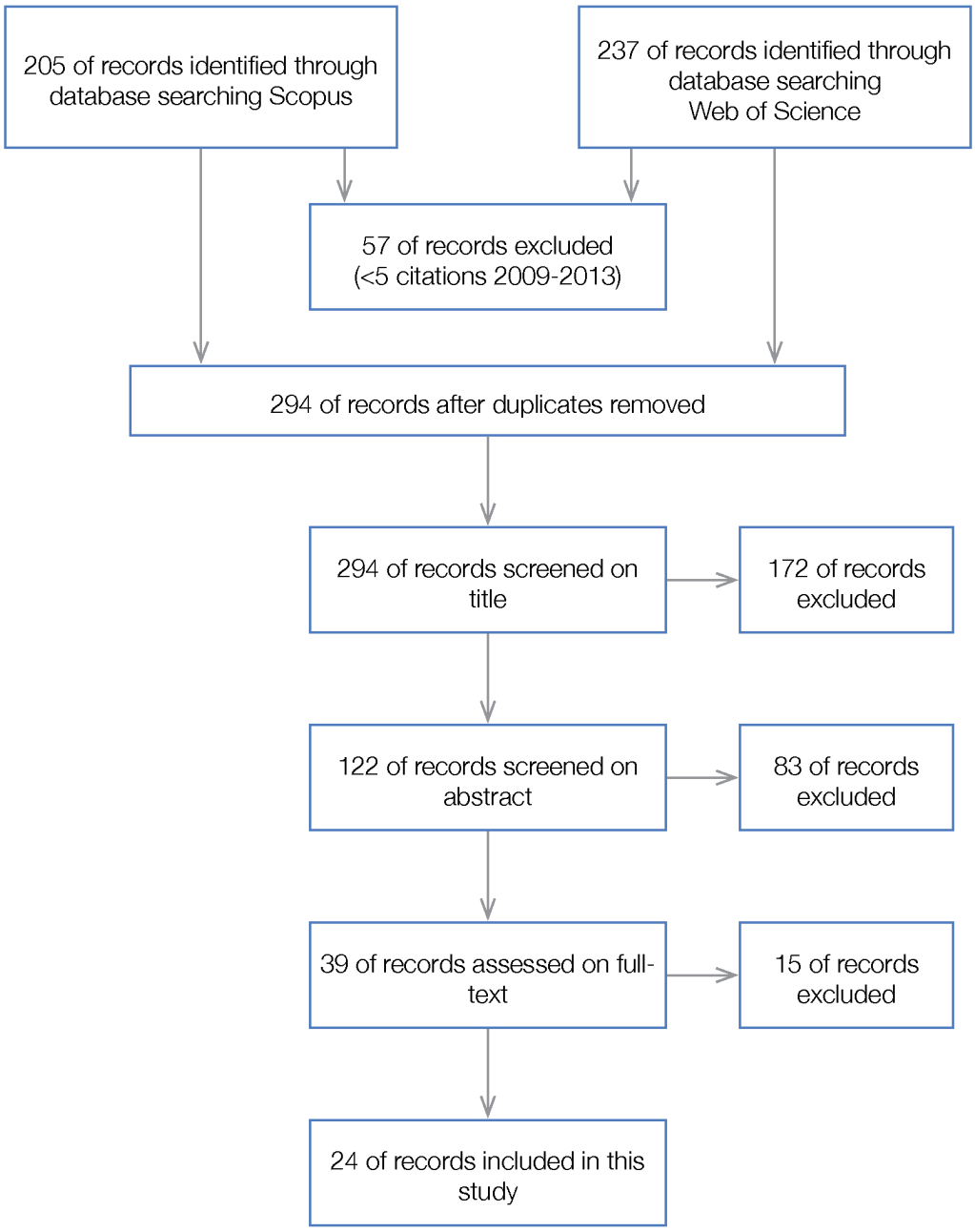

Figure 5. Flow chart of records for the SLR.

Based on the exclusion criteria 172 records were excluded of the 294, and 122 records were screened on the basis of abstract. On the basis of exclusion criteria 83 records were excluded, and the full-text of 39 records was assessed for inclusion in this study. Of the 39 records 24 were included in this thesis, based on inclusion criteria, and 15 records were excluded.

As a result of concept coding, with code 'interpretation', a total of 17 interpretations of 'impact' were identified in 11, out of 24, records. Furthermore, there were 117 mentions of 13 different areas were identified by the concept 'Area', and 41 mentions of 13 different scales were identified by the concept 'Scale' (Table 1).

One of the records included in this study, *How do we define the policy impact of public health research? A systematic review* by Alla et al. (2017) included a data set of 102 interpretations of 'research impact'. The data set produced by Alla et al. was a result of a SLR of both peer-reviewed and grey literature defining research impact, with a "specific focus on the applicability of definitions to advancing an academic understanding of how evidence informs health policy" (Alla et al., 2017). Furthermore, the search strategy and inclusion criteria were quite similar, except for the fact that Alla et al. focussed on health policy and included grey literature. Furthermore, comparable inclusion criteria and criteria for identification of interpretations of 'impact' were used. The inclusion of this data set would allow for effortless inclusion of interpretations of grey literature, and would increase sample size for quantitative analysis, strengthening statistical power to draw conclusions. Therefore, this data set was included in this study, as an addition to the previously found interpretations of 'impact'.

The data set from Alla et al. included multiple duplicates of interpretations, the data set was therefore further refined to only include unique interpretations of 'impact', which resulted in 47 unique interpretations mentioned in a total of 37 records. All 47 interpretations were concept-coded for the concepts 'Area' and 'Scale' and added to the current data set; concept coding for the concept 'Interpretation' was not performed, since this would be redundant. There were 143 mentions of 14 different areas were identified by the concept 'Area', and 77 mentions of 25 different scales were identified by the concept 'Scale' (Table 1).

Table 1. Overview of results of concept coding for SLR and included interpretations from Alla et al. (2017).

Source	SLR	Alla et al. (2017)
Records	24	37
# of interpretations	17	47
# of records	11	37
# of scales (# of mentions)	13 (41)	25 (77)
# of records	12	17
# of areas (# of mentions)	13 (117)	14 (143)
# of records	23	26

All interpretations (n = 64) included in this study were further analysed for the presence of the five themes (*Bias, Demonstrable, Area, Scale* and *Directness*) (Table 2). A full list of interpretations and encoding of the five themes is included in *Appendix II – Interpretations of 'impact'*.

Table 2. Overview of result of encoding all interpretations for the four parameters Bias, Demonstrable, Area and Scale, and for Directness.
* In 61 interpretations there was no explicit mention of direct or indirect impact

Parameter	Present / Direct	Absent / Indirect	Total
Bias	23	41	64
Demonstrable	20	44	64
Area	47	17	64
Scale	24	40	64
Directness	1	2	3*

2.2.2 Guidelines for an interpretation of impact

2.2.2.1 Bias

The first theme used to analyse the interpretations of impact was *Bias* and relates to interpretations of impact that have a bias towards a preferred type of impact. Bias was present in 23 out of 64 interpretations, approximately 36%. All 23 instances of bias were that where identified were of positive nature. Although 23 instances of bias were encoded, the word 'benefit' and derivatives of that word were mentioned 30 times, indicating that some definitions included both biased and neutral terms to describe impact.

Negative impact was mentioned only once, in the interpretation given by Reed (2016):

> *"By 'impact', we are talking about beneficial changes that will happen in the real world (beyond the world of researchers) as a result of your research. This can include 'negative impacts' such as evidence that prevents the launch of a harmful product or law. Impacts may occur in the immediate or long-term future, and there can be challenges tracking and attributing impacts, which this book will help you explore."*

It is hard to say that all research outcomes are positive, and that therefore all research impact is positive. Research results can also be used in a negative way and can therefore have negative impact as well. A prime example of this is nuclear physics. While it has led to great advances in medical diagnostics and cancer treatments, it has also led to weapons of mass destruction, like atom bombs. Alla et al. (2017) also report that a 'positivity bias' may be limited in pursuing academic understanding of how evidence impacts policy. Of course, as a researcher you hope that research will (only) have positive impact, but it would be naive to exclude negative impact from an interpretation of impact. As Woolcott et al. (2019) state: "*Any such framework [an impact framework] should include an impact assessment that is neutral, in the sense of being able to identify (unintended) negative effects as well as positive benefits*." Therefor the interpretation of impact should remain (objective and) neutral/unbiased, allowing for the inclusion of both positive and negative impacts of research. This is in agreement with the trend observed in the quantitative analysis. Therefore, a first recommendation is that an interpretation of impact considers both positive and negative impact.

2.2.2.2 Demonstrable

Secondly, interpretations of 'impact' were analysed for the need of impact to be demonstrable, by the theme *Demonstrable*. Presence of demonstrability was identified in 20 out of 64 interpretations, approximately 31%.

Complications could arise in the situation where only demonstrable impact is included, due to the 'attribution problem' (Armstrong & Alsop, 2010). As Kelly (2012) mentions, it is often difficult and frequently impossible to pin-point the evidence of an actual effect, change or benefit. It therefor raises the question to what extent changes of outcomes of interest can be attributed to a particular intervention (Leeuw & Vaessen, 2009), e.g. it is difficult to prove that a particular change in policy was solely or even partially attributable to a single piece of research or record. It could also be that multiple research groups or people worked a similar topic and have published similar results. Which raises the question to whom you attribute the 'impact'. Since this is impossible to answer, it would be best to steer away from only looking at demonstrable impact.

Another part of the attribution problem is the non-linearity of impact (Armstrong & Alsop, 2010). Achieving social impact is considered a complex, uncertain and long-term process (Miettinen, Tuunainen, & Esko, 2015). However, as Martin (2011) explains, 'impact' and its evaluation often implicate a linear model "of how knowledge from an individual piece of research is subsequently taken up and used". As he has shown over the years, this linear model rarely applies. This is also illustrated by the LSE Public Policy Group (2011) in *Maximizing the impacts of your research: a handbook for social scientists* (Figure 6). Although this is developed for social scientists, and thus social science, the process of performing research and the pathway from research outcomes to impact is in essence similar. Retracing the reverse path, starting at the impact back to its original study, in a non-linear system, will be difficult. So, in a scenario where the impact is interpreted to only include demonstrable impact, and the impact cannot be traced back to the research, there would be no proof, and thus no impact. The non-linearity of impact and attribution problem together make a case for the integration of non-demonstrable in the interpretation of 'impact'. This is also in agreement with the trend observed in the quantitative analysis. Therefore, a second recommendation is that an interpretation of impact considers both demonstrable and non-demonstrable impact.

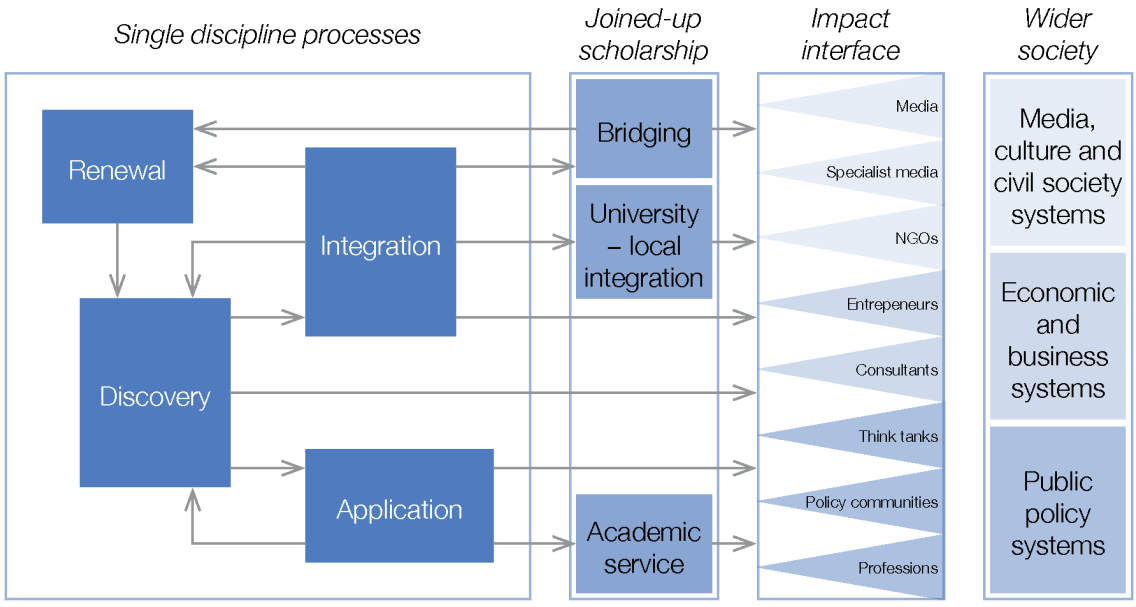

Figure 6. A schematic representation of the complexity and non-linearity of impact that originates from performed research (adapted from LSE Public Policy Group (PPG), 2011, p. 153).

2.2.2.3 Area

The third theme analysed for the interpretations of impact was *Area*, relating to the presence of specifications for the area of impact. In 47 of the 64 interpretations area-specification was included, approximately 73%. Great diversity was noticed in the amount of areas mentioned, varying between 'beyond academia', leaving many options, and 'society and economy', leaving little options.

Interpretations of impact that evolved from the REF-interpretation of impact, as original references are shown in *Additional file 1. Definitions of research included in this study* of Alla et al. (2017), include the following areas, namely: "economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia" (Bannister & Hardill, 2013; Chandler, 2013; Détourbe, 2016). These areas are also identified in the definition or the Australian Research Council (2018). Interestingly, the REF is developed by the Higher Education Funding Council for England (HEFCE) and attributes 20% of the score for each higher education institution (HEI) based on impact (Greenhalgh & Fahy, 2015). However, in the definition it stresses that impact is only accounted for "beyond academia". Hartwell et al. (2013) and Khazragui et al. (2015) also describe that impact on teaching undergraduate or postgraduate students and advancement of academic knowledge within universities cannot be claimed as impact based on the REF interpretation. This exclusion is in direct conflict with the purpose of a university, and therefore it is striking that the definition only considers impact beyond academia. Moreover, linking funding to impact that does not consider the primary task and primary impact of an institution, is incorrect.

Specifying in what area(s) impact of research is found can also narrow the scope of where researchers focus their research. Therefor it would be best to either include all areas for impact, or don't mention them in the interpretation at all, but provide the current consensus on areas of impact in an overview or framework. The latter would also leave space for the development/addition of new areas, without changing the interpretation. This is counter to the trend observed in the analysed interpretations, but it would improve the interpretation of impact. Therefore, a third recommendation is than an interpretation of impact is to refrain from limitations in areas of impact, by not mentioning them in the interpretation.

2.2.2.4 Scale

Similar to *Area*, *Scale* was analysed as the fourth theme of interpretations of impact. In 24 of the 64 interpretations scale-specification was included, approximately 38%. Most interpretation specified a few scales of impact, while others added 'any geographic location', which opened up the possibility to include more scales of impact, but still remained somewhat vague. Since impact can be experienced on any (and every) level of scale, either all should be included in the interpretation of impact, or none, but provide the current consensus on scales of impact in an overview or framework. Here too, the latter would leave space for the development and addition of new scales, without changing the interpretation. Not specifying scales of impact is in agreement with the trend observed in the quantitative analysis. Therefore, a fourth recommendation is that an interpretation of impact is to refrain from limitations in scales of impact, by not mentioning them in the interpretation.

2.2.2.5 Direct/indirect

Finally, *Directness* of impact of the interpretations was analysed. In only 3 out of the 64 interpretations direct impact or indirect impact was explicitly mentioned. In order to further investigate *Directness* of the interpretations, an interpretation of *Directness* for each interpretation was made by the author of this study, based on the sentiment. Four examples, two for direct impact and two for indirect impact, are shown in Text Box 2. This resulted 42 instances of direct impact and 22 instances of indirect impact.

Since a relation was assumed between demonstrable impact and direct impact, and between non-demonstrable impact and indirect impact, in encoding *Demonstrable*, a comparison is made

between *Demonstrable* and *Directness*. It was therefor expected that demonstrable, direct impact and non-demonstrable, indirect impact would be the main categories.

The result of this comparison yielded approximately three approximately equal-sized groups: demonstrable direct impact (18), non-demonstrable indirect impact (20) and non-demonstrable direct impact (24), and one small group: demonstrable indirect impact (2) (Table 3). The findings that demonstrable direct impact and non-demonstrable indirect impact were in agreement with the expectations. However, the biggest identified group was non-demonstrable direct impact. This seems very contradictory and raises the question how research can have direct impact and be non-demonstrable. Similarly, the group of demonstrable indirect impact raises the question how research can have an indirect impact, but still be demonstrable.

The attribution problem and non-linearity of impact described previously in *Demonstrable*, relates closely to indirect impact, since in both cases there is no evidence that supports the claim of a relation between an (observed) impact and a study. Based on the recommendation given in *Demonstrable*, a fifth recommendation for an interpretation of impact, related to *Directness*, is to consider both direct and indirect impact.

Examples of interpretations of impact interpreted based on sentiment as direct impact:

> *"Here, impact has been defined as including patents, licensing agreements, liaison with industry, authorised consultancy work, campus companies, placement of students or graduates, or cultural, economic and social impacts."*
>
> *Rau, Goggins, & Fahy (2018)*

> *"Similarly HEFCE and Star Metrics have operationalised research impact as the benefits and returns that research brings to the economy, environment, international and social arenas, public policy and services, and to the quality of life, culture and health of individuals and communities."*
>
> *Halse & Mowbray (2011)*

Examples of interpretations of impact interpreted based on sentiment as indirect impact:

> *"Impact: these are the contributions of and benefits to the scientific community (with the progression of knowledge) and to society (with practical consequences on the progression of knowledge)."*
>
> *Lima & Wood (2014)*

> *"Impacts, often called outcomes, are the effects of the research on the research field or within society."*
>
> *Drew et al. (2016)*

Text Box 2. Examples of interpretations of direct and indirect impact in interpretations of impact.

Table 3. Comparison of Demonstrable and Directness for 64 interpretations of impact.

Demonstrable	Present	Absent	Total
Direct impact	18	24	42
Indirect impact	2	20	22
Total	20	44	64

2.2.2.6 Interpretations matching recommendations

Based on an analysis of the presence of these five themes recommendations were given for formulating a general interpretation of 'impact'. It is recommended that an interpretation of impact considers both positive and negative impact, encoded as '0' in the theme *Bias*; considers both demonstrable and non-demonstrable impact, encoded as '0' in the theme *Demonstrable*; refrains from limitations in areas of impact and scales of impact, encoded as '0' in both themes *Area* and *Scale*; and considers both direct and indirect impact, encoded as '0' in the theme *Directness*. This results in the five-digit code '00000'. As each of the interpretations of impact was encoded with a five-digit code, the interpretations matching the requirements were easily identified. Only three interpretations with code '00000' were present in the dataset (Text Box 3).

Interpretations of impact that are neutral, include demonstrable and non-demonstrable impact, do not impose limitations on areas and scales of impact, and include both direct and indirect impact:

> *"For purposes of program and portfolio evaluation, we define impacts to be the benefits or changes resulting from scientific research, program activities or outputs."*
>
> (Drew et al., 2016)

> *"The LSE's maximising impact handbook, though, defines 'a research impact' as 'an occasion of influence' rather than what might happen as a result of that influence."*
>
> *(Association of Commonwealth Universities (ACU), 2016)*

> *"In order to define research impact, the spectrum of impact from conceptual to instrumental set out by Nutley et al (2007) was used as a starting point. Changes in awareness, knowledge and understanding, ideas attitudes and perceptions, and policy and practice as a result of research."*
>
> *(Morton, 2015)*

Slightly deviating interpretation of impact:

> *Research impact is a direct or indirect contribution of research processes or outputs that have informed (or resulted in) the development of new (mental) health policy/practices, or revisions of existing (mental) health policy/practices, at various levels of governance (international, national, state, local, organisational, health unit).*
>
> *Alla et al. (2017)*

Text Box 3. Interpretations of impact that follow the five recommendations.

In these first three definitions the words ‘benefits’, ‘changes’ and ‘influence’ are used to describe impact. Based on the way the encoding of interpretations of ‘impact’ was performed, it was possible that words with positive connotations were still present, which is the case for the interpretation given by Drew et al.; the word ‘benefits’ is used in the is interpretation. This interpretation also specifies that it is for the purpose of evaluating programs and portfolios, whereas the other two interpretations do not specify a specific use. The interpretation of the Association of Commonwealth Universities leaves room for interpretation in what the influence of research is, but therefore also remains a bit vague. The word ‘influence’ however, is preferred over ‘changes’ as Drew et al. used. The interpretation given by Morton, which is based on an interpretation by Nutley, already includes some of the indicators of impact into its interpretation by stating ‘changes in awareness’. Although this helps in identifying impact, they do feel out of place. Lastly, the interpretation by Alla et al. does make a good start, as it includes both direct and indirect impact, however this interpretation is specified for health policy/practices. Nonetheless, this interpretation is used as inspiration for a general interpretation of ‘impact’.

2.2.3 Selecting areas and scales of impact

Based on the 64 interpretations, and accompanying records, various areas and scales for impact were identified by concept coding. In the following sections a selection is made for the main areas and scales.

2.2.3.1 Scale

The records identified via SLR were concept-coded for ‘Scale’ and its sub-concepts, as was done for all interpretations identified from *Additional information 1. Definitions of research included in this study* of Alla et al (2017). In total 118 mentions of scales were identified in 29 records, divided over 29 sub-concepts, i.e. scales (Table 4). The 29 identified scales were: Individual (17), Community (15), Organisation (13), Nation (11), International (8), Local (8), Region (8), Audience (3), Beneficiary (3), Government (3), Society (3), Constituency (2), Geographic location (2), Global (2), Health system (2), Other (2), Patient (2), Society at large (2), Society in general (2), Business (1), European (1), Health unit (1), Industry (1), People (1), State (1), System (1), The taxpayer (1) and Widespread (1).

To narrow down the mentioned scales into a smaller, more manageable quantity, which is also suited for the development of a tool, combinations between scales were made and a lower limit of at least 5 mentions was set. If scale were mentioned in less than 5 times it was expected that they were not likely to be important. One possibility of a combination was found to present, namely Society, Society at large and Society in general, which results in a combined 7 mentions.

Scales that were excluded by setting a lower limit were: Audience, Beneficiary, Government, Constituency, Geographic location, Global, Health system, Other, Patient, Business, European, Health unit, Industry, People, Population, State, System, The taxpayer and Widespread. Scales like Audience, Beneficiaries, Constituency, Geographic location, Other, System, The taxpayer and Widespread, are too vague, and will not benefit a framework when included. Parker & Teijlingen (2012) give an indication of whom beneficiaries might be: “such as: individual social workers or users of social work services, social services agencies and voluntary or private organisations, communities (however defined), policy-makers, politicians, law makers, regional development groups, and other bodies including the natural environment.” Some of these beneficiaries as mentioned by Parker & Teijlingen were also mentioned separately, like organisations and communities, and were thus still included. Other scales were found to be too specific, like: Health system, Patient and Health unit. The remaining scales not exceeding the lower limit, Government, Global, People, Population, State, Business and Industry, can be recognised to some extend in the scales that would be included in the framework; Government, Business and Industry in Organisation, Global in International, State in Region, and People and Population in Community. Refinement of scales resulted in the selection of the following main scales: i) Individual, ii) Community, iii) Organisation, iv) Nation, v) International, vi) Local, vii) Region and viii) Society.

Table 4. All sub-concepts coded under the concept 'Scale', during concept coding, and the identified amount of mentions in the records and interpretations.

Scale (118 mentions in 29 records)	#		
Individual	17	Other	2
Community	15	Patient	2
Organisation	13	Society at large	2
Nation	11	Society in general	2
International	8	Business	1
Local	8	European	1
Region	8	Health unit	1
Audience	3	Industry	1
Beneficiary	3	People	1
Government	3	Population	1
Society	3	State	1
Constituency	2	System	1
Geographic location	2	The taxpayer	1
Global	2	Widespread	1
Health system	2		

2.2.3.2 Area

The records identified via SLR were concept-coded for 'Area' and its sub-concepts, which was also done for all interpretations identified in the *Additional information 1. Definitions of research included in this study* of Alla et al (2017). In total 260 mentions of areas were identified in 49 records, divided over 15 sub-concepts, i.e. areas (Table 5). The 15 identified areas were: Economic (37), Political (31), Societal (31), Cultural (28), Environmental (26), Health (24), Academic (21), Social (19), Quality of life (17), Educational (8), Industrial (7), Scientific (7), Technological (2), Industrial development (1) and Production (1).

To narrow down the mentioned areas into a smaller, more manageable quantity, which is also suited for the development of a tool, combinations between areas were made. To this, Scientific and Academic were combined, since both are concerned with the understanding of matter, and henceforward referred to only as Scientific. All areas that were involved in applying knowledge, identified as: Industrial, Technological and Production, were combined in the area Technological. Both areas Health and Quality of life are involved with the well-being of individuals or groups, in any of life's features, were combined in the area Health. The areas Societal and Social were combined in Societal, because both are involved in social relations between individuals and groups. The area International development did not fit within any of the other areas identified and was only mentioned once out of 280 mentions. Based on its occurrence, International development was deemed unlikely to be important, and was therefore excluded as an area for impact in this study. Refinement of areas resulted in the selection of the following main areas of impact: i) Scientific, ii) Technological, iii) Economic, iv) Societal, v) Political, vi) Cultural, vii) Health, viii) Environmental and ix) Education.

Table 5. All sub-concepts coded under the concept 'Area', during concept coding, and the identified amount of mentions in the records and interpretations.

Area (260 mentions in 49 records)	#		
Economic	37	Quality of life	17
Political	31	Educational	8
Societal	31	Industrial	7
Cultural	28	Scientific	7
Environmental	26	Technological	2
Health	24	International development	1
Academic	21	Production	1
Social	19		

2.2.4 Indicators of impact per area

In the following sections indicators of impact, found in records and in all interpretations of impact in *Additional information 1. Definitions of research included in this study* of Alla et al (2017), are discussed per selected main area.

2.2.4.1 Scientific

This area is mainly concerned with the production, understanding and dissemination of knowledge. Firstly an indicator is the (significant) advances in academic knowledge within higher education institutes (Jones & Cleere, 2014; Khazragui & Hudson, 2015) and in understanding method, theory and application (Shaw & Holland, 2014). This could be visible in the activity of the institute and/or researcher, in the number of peer-reviewed publications (Banzi, Moja, Pistotti, Facchini, & Liberati, 2011; Harland, 2013) and quality parameters such as impact factors, download number and citation impact (Banzi et al., 2011; K. M. Smith, Crookes, & Crookes, 2013). Other indicators include the identification of knowledge gaps (Eisenberg, 2001), contribution to the formation of disciplines, training and capacity building (Jones & Cleere, 2014) or changes in awareness, practice, attitudes, ideas and perceptions as a result from research (Morton, 2015; Schnitzler et al., 2016; Walter, Davies, & Nutley, 2003). The dissemination of knowledge (to the public) (Bozeman & Youtie, 2017; Hartwell et al., 2013; UK Research and Innovation, 2014), and the number of (foreign) co-authors (Banzi et al., 2011; Harland, 2013) could also be an indicator of impact in the academic and scientific area. Other related indicators could be participation in committees for the evaluation of scientific studies, awards, participation as a guest researcher in local and international institutions (Lima & Wood, 2014).

2.2.4.2 Economic

This area is mainly concerned with enhancement of economic performance and benefits. Indicators for the economic area include economic benefits such as: economic rent (such as salaries and employments), licensing returns and other incomes from industry, products and spin-out companies (also found in *Technological*) (Banzi et al., 2011; Ovseiko, Oancea, & Buchan, 2012; Qin, 2010). Generating new jobs and contributing to improved workforce participation and economic growth and economic competitiveness are also indicators of economic impact (Canadian Institute of Health Research (CIHR), 2005; Jones & Cleere, 2014; Mitchell, 2019; UK Research and Innovation, 2014). On an organisational level, indicators could be the contribution to the sale price of a product and to the firm's costs and revenues (Banzi et al., 2011; Jones & Cleere, 2014). Finally, there are indicators that overlap with the *Health* area, such as health benefits in quality-adjusted life year (QALY) and patient-reported outcome measures (PROMs) per health care dollar and as well-being (Banzi et al., 2011).

2.2.4.3 Technological

This area is mainly concerned with the application of knowledge to develop products, processes or businesses. A first indicator of this area is the contribution to the creation of new businesses, improving the performance of current businesses or the commercialisation of new products and processes (Chandler, 2013; Jones & Cleere, 2014; Ovseiko et al., 2012; UK Research and Innovation, 2014). This can also be seen as spin-out companies from academia, co-authored papers between industry and academia from collaborative research, and patents granted and/or licenses awarded and brought to the market (Ke, 2018; Ovseiko et al., 2012). Another indicator could be the acquisition of funds (from overseas or global businesses) for innovative projects (Lima & Wood, 2014; Ovseiko et al., 2012). Lastly, indicators could be the adoption of management tools and methods by public, private and social organisations, receiving public recognition for the contribution to creating innovations (Lima & Wood, 2014) or receiving income from intellectual property (also found in *Economic*) (Qin, 2010).

2.2.4.4 Societal

This area is mainly concerned with the welfare of society. Indicators here include the contribution to community welfare, behaviour, practices and activities of people and groups (Jones & Cleere, 2014; Parker & van Teijlingen, 2012; Sumner, Crichton, Theobald, Zulu, & Parkhurst, 2011). Other indicators are measures that improve social equity, inclusion and cohesion, cultural freedom and vitality (Oancea, Florez Petour, & Atkinson, 2017; Ovseiko et al., 2012), aiding in national security by application of new security technologies or practices (Ovseiko et al., 2012) and allowing for the development of a knowledge-based society (Canadian Institute of Health Research (CIHR), 2005).

2.2.4.5 Cultural

This area is mainly concerned by values and beliefs of people and engagement of the general public. An indicator for this area could be the contribution to the formation of values, understanding of ideas and reality or beliefs (Jones & Cleere, 2014; Parker & van Teijlingen, 2012; Sumner et al., 2011). This also relates to the (increased level of) public engagement with science, research and/or researcher, and the contribution to the quality of public and professional discourse and debate (Oancea, 2013; Ovseiko et al., 2012; Sumner et al., 2011; Wilkinson, Gallagher, & Smith, 2012). Other indicators are an increase in the creative output of the public (Brewer, 2013; Jones & Cleere, 2014), the raising of consciousness (Walter et al., 2003) and the broadening of participation of underrepresented groups, for example gender, ethnicity, disability, geographic, etc. (Bozeman & Youtie, 2017).

2.2.4.6 Political

This area is mainly concerned with the relation to policy makers and the development of policies and guidelines. First and foremost, and indicator is a better informed public policy-making and/or improved public services (Brewer, 2013; Lima & Wood, 2014; Ovseiko et al., 2012; UK Research and Innovation, 2014). This can be in form of supplying reports, opinions and other documents (Banzi et al., 2011; Jones & Cleere, 2014; Lima & Wood, 2014; Watermeyer, 2014), participation in public policy advisory committees (Lima & Wood, 2014; Ovseiko et al., 2012), alerting policy makers and practitioners to an issue (K. E. Smith & Stewart, 2017; Walter et al., 2003) or changing the language/discourse we use to discuss an issue (K. E. Smith & Stewart, 2017). This can lead to changes in current legislation, regulations or government policy (Ovseiko et al., 2012) or to the creation of new legislation (Chandler, 2013; Cohen et al., 2014) providing political stability (Jones & Cleere, 2014; Watermeyer, 2014). Other activities that can be pursued, which can be used as an indicator, are the organisation of events that mobilize opinion and decision makers (Lima & Wood, 2014), disseminate information packages, and participate in media (Banzi et al., 2011). Finally, public recognition of contribution to the analysis or formulation of public policies can be seen as an indicator (Lima & Wood, 2014).

2.2.4.7 Environmental

This area in mainly concerned with the environmental sustainability and stability. Indicators here are the reduction, prevention and/or avoidance of harm or disease spreading, resources and or accidents (Campbell et al., 2015; Greenhalgh & Fahy, 2015; Jones & Cleere, 2014; Mitchell, 2019; Parker & van Teijlingen, 2012). Other indicators could be the contribution to sustainable development (including environment sustainability) (Ovseiko et al., 2012) and contribution to the management of the environment, like natural resources, environmental pollution, climate and meteorology (Jones & Cleere, 2014), and food, energy and water security (Campbell et al., 2015).

2.2.4.8 Health

This area is mainly concerned with health and well-being, and also includes quality of life indicators. A first indicator is the contribution to public health, life expectancy and the prevention of illness (Jones & Cleere, 2014). This also includes epidemiological data, QALYs and PROMs, determinants of health, e.g. risk factors, educational and social level of cohesion and pollution (Banzi et al., 2011). Patient related indicators include: patient satisfaction, length of patient stay and the development of new or improved drugs, treatments and other medical interventions or numbers of advanced phase clinical trials (Banzi et al., 2011; Ovseiko et al., 2012). Other indicators include improved health systems and services, waiting lists, compliance to clinical guidelines, reduction of effects and complications, reduction of treatment costs and changes to clinical or healthcare training, practice and guidelines (Cohen et al., 2014; Eisenberg, 2001; Ovseiko et al., 2012). Finally, indicators could be improved general well-being and changes to public behaviour towards medicine (Cohen et al., 2014; Weitkamp, 2018).

2.2.4.9 Education

This area is mainly concerned with the education and training of students at higher education institutes and the general public. A first indicator here is the contribution to curricula (Khazragui & Hudson, 2015; Oancea, 2013) qualifications (Jones & Cleere, 2014), and the development of pedagogical tools like textbooks (the adoption by educational institutions of this material), cases, games and/or software (Jones & Cleere, 2014; Lima & Wood, 2014), and publications on topics related to teaching and learning (published in scientific journals) (Lima & Wood, 2014). Another indicator, as a result of teaching, is the delivery of highly skilled people that move between academia and industry, and the employment post-doctoral researchers in industry (Ovseiko et al., 2012). Furthermore there is capacity building by means of staff employment (PhD, Master students, researchers and general staff members), funding and infrastructure (Banzi et al., 2011), which could be used as an indicator for *Education and Teaching*. Other indicators could be increasing the general public's scientific literacy level, enhancing communication and understanding among a broader audience about the nature and benefits of research (also promoting teaching, training and learning), and allowing researchers to learn themselves about educational theory and increasing their teaching skills (Bozeman & Youtie, 2017; McCann, Cramer, & Taylor, 2015).

2.3 Chapter conclusion

This chapter aimed to answer RQ1 and RQ2, by a systematic literature review, concept coding, encoding and quantitative analysis.

RQ1 *What can or may impact entail based on literature and how does this translate into a general interpretation of 'impact'?*

Based on the interpretations of impact, five themes were identified that were either present or absent in all interpretations. Namely the theme *Bias*, which considers bias in the word describing impact; the theme *Demonstrable*, which considers the demonstrability of impact; the theme *Area*, which considers area specification of where there is impact; the theme *Scale*, which considers scale specification of where there is impact; and the theme *Directness*, which considers the type of impact, either direct or indirect. Thus, impact can entail bias, demonstrability, areas and scales of impact, and direct and indirect impact.

Furthermore, impact may be found in various areas, as identified in this study, namely: scientific, technologic, economic, societal, cultural, political, environmental, health and education. Additionally, research may have impact on various levels of scale, namely on the level of an individual, local, region, community, organisation, nation, international, and/or society.

Finally, based on an analysis of the presence of these five themes recommendations were given for formulating a general interpretation of 'impact'. It is recommended that an interpretation of impact considers both positive and negative impact, thus remains neutral; considers both demonstrable and non-demonstrable impact; refrains from limitations in areas of impact; refrains from limitations in scales of impact; and considers both direct and indirect impact. These five recommendations translate into the following general interpretation of 'impact':

> *Research impact is a direct or indirect influence of research outcomes*

RQ2 *What are possible indicators for impact by scientists?*

An overview of all previously mentioned indicators per each of the nine selected main areas is presented below, in Table 6.

Table 6. Possible indicators of impact categorised by areas of impact.

Scientific	Technological	Economic	Societal	Cultural
- (Significant) advances in academic knowledge within higher education institutes and in understanding method, theory and application. Visible in the activity of the institute and/or researcher, in the number of peer-reviewed publications and quality parameters such as impact factors, download number and citation impact. - Identifying knowledge gaps - Contributing to the formation of disciplines, training and capacity building - Changing awareness, practice, attitudes, ideas and perceptions as a result from research - The dissemination of knowledge (to the public) - The number of (foreign) co-authors - Participating in committees for the evaluation of scientific studies, awards, or participating as a guest researcher in local and international institutions	- Contributing to the creation of new businesses, improving the performance of current businesses or the commercialisation of new products and processes - Number of spin-out companies from academia, co-authored papers between industry and academia from collaborative research, and patents granted and/or licenses awarded and brought to the market - Acquiring funds (from overseas or global businesses) for innovative projects - Aiding in the adoption of management tools and methods by public, private and social organisations, - Receiving public recognition for the contribution to creating innovations - Receiving income from intellectual property	- Increasing economic benefits such as: economic rent (such as salaries and employments), licensing returns and other incomes from industry, products and spin-off companies - Generating new jobs and contributing to improved workforce participation and economic growth and economic competitiveness - Contributing to the sale price of a product and to the firm's costs and revenues - Increasing health benefits in quality-adjusted life year (QALY) and patient-reported outcome measures (PROMs) per health care dollar and as well-being	- Contributing to community welfare, behaviour, practices and activities of people and groups - Developing measures that improve social equity, inclusion and cohesion, cultural freedom and vitality - Aiding in national security by application of new security technologies or practices - Allowing for the development of a knowledge-based society	- Contributing to the formation of values, understanding of ideas and reality or beliefs - (Increasing) the level public engagement with science, research and/or researcher, - Contributing to the quality of public and professional discourse and debate - Increase in the creative output of the public - Raising of consciousness - Broadening of participation of underrepresented groups, for example gender, ethnicity, disability, geographic, etc.

Table 6. Possible indicators of impact categorised by areas of impact. (Continued)

Political	Environmental	Health	Education
- Aiding in a better informed public policy-making and/or improved public services, in the form of supplying reports, opinions and other documents, participating in public policy advisory committees, alerting policy makers and practitioners to an issue or changing the language/discourse we use to discuss an issue - Changing current legislation, regulations or government policy, creating new legislation or providing political stability - Organising events that mobilize opinion and decision makers - Disseminating information packages - Participating in media - Receiving recognition of contribution to the analysis or formulation of public policies	- Reducing, preventing and/or avoidance of harm or disease spreading, resources and or accidents - Contributing to sustainable development (including environment sustainability) - Contribution to the management of the environment, like natural resources, environmental pollution, climate and meteorology and food, energy and water security	- Contributing to public health, life expectancy and the prevention of illness, also by developing epidemiological data, QALYs and PROMs, determinants of health, e.g. risk factors, educational and social level of cohesion and pollution - Patient satisfaction levels, length of patient stay, and the development of new or improved drugs, treatments and other medical interventions or numbers of advanced phase clinical trials - Improving health systems and services, waiting lists, compliance to clinical guidelines, reduction of effects and complications, reduction of treatment costs and changes to clinical or healthcare training, practice and guidelines - Improving general well-being and changes to public behaviour towards medicine	- Contributing to curricula, qualifications, the development of pedagogical tools like textbooks (the adoption by educational institutions of this material), cases, games and/or software, and publications on topics related to teaching and learning (published in scientific journals) - Delivering highly skilled people that move between academia and industry, and the employment post-doctoral researchers in industry - Capacity building by means of staff employment (PhD, Master students, researchers and general staff members), funding and infrastructure - Increasing the general public's scientific literacy level, enhancing communication and understanding among a broader audience about the nature and benefits of research (also promoting teaching, training and learning), - Allowing researchers to educate themselves about educational theory and increasing their teaching skills

3 Identifying enablers and barriers of impact

This chapter aim to answer the following research question:

RQ3 *What are potential enablers for generating impact and what are potential barriers that hamper generating impact according to scientists?*

In order to answer RQ3 semi-structured interviews were conducted with academic staff members – scientists – of the department of Biotechnology, TU Delft, and concept coding was used to identify possible enablers and barriers of impact. Furthermore, preliminary focus areas and scales were identified by quantitative analysis. Detailed descriptions of the methodologies used are given in section 3.1. Based on the semi-structured interviews focus areas and scales for biotechnologists were identified and their point of view on impact, as well as possible enablers and barriers for impact. These outcomes are presented and discussed in section 3.2. This is followed by an answer to RQ3 in the concluding section 3.3. A schematic overview of methods used and outcomes are shown in Figure 7.

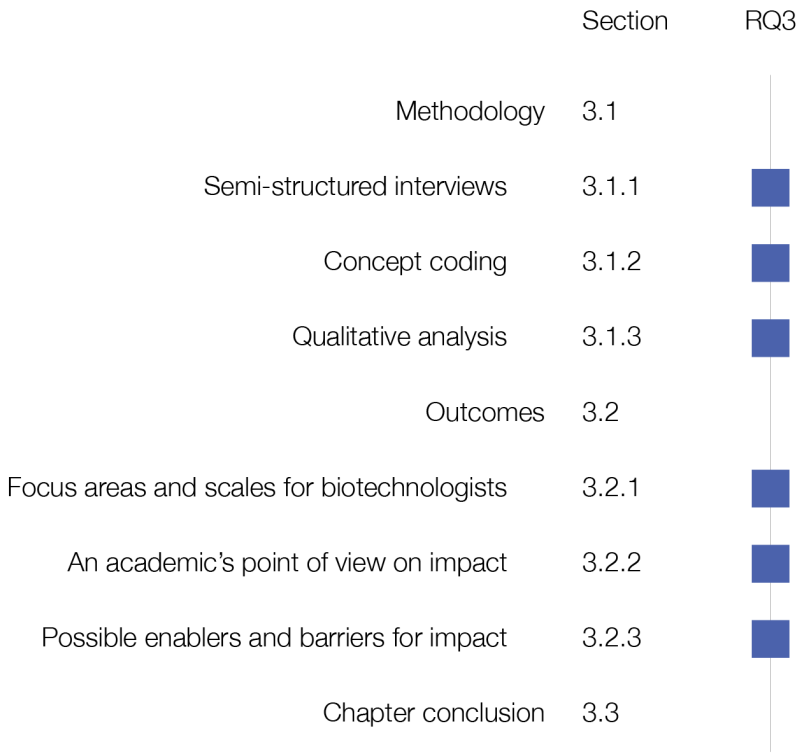

Figure 7. Schematic overview of the structure of Chapter 3, including methods used, outcomes and chapter conclusion.

3.1 Methodology

To identify enablers and barriers of generating impact, semi-structured interviews were conducted with academic staff of the Department of Biotechnology, TU Delft. Previously selected areas and scales (Chapter 2.2.3) were used to develop questions for the used interview protocol. Interviews were transcribed and concept-coded for further analysis. From this analysis focus areas and scales were identified, as well as the point of view of biotechnologists on impact. Furthermore, enablers and barriers were identified and where possible combined to form a set of possible overarching enablers.

3.1.1 Semi-structured interviews

Based on the results of preliminary interviews with two PhDs and two postdocs of the department of Biotechnology at TU Delft, it was determined that predicting the impact of research was close to impossible. Therefore, it was chosen to reflect on the impact of previously performed research, rather than to speculate about the possible impact of current research. To identify possible enablers and barriers for the generation of impact, semi-structured interviews were conducted. It was chosen to conduct semi-structured interviews since this would give participants the freedom to elaborate on topics, since impact is such a complex topic.

Interviews were conducted with associate and full professors of the Department of Biotechnology of TU Delft. Since this study is part of a graduation project for a Double Degree between Communication Design for Innovation (CDfI) and Life Science & Technology (LST), it was chosen to interview staff members of the Department of Biotechnology. Existing connections to staff members allowed for the quick set-up of interviews, and knowledge of, and experience in, the field of Biotechnology, acquired in the master program LST, allowed for the discussion and understanding of research projects at a detailed level. It was chosen to interview associate and full professors because they have more experience in performing and overseeing research and/or more experience in collaborating with industry than other members of the faculty. All associate and full professors (13) of the Department of Biotechnology, TU Delft, were invited to participate, however only 10 responded, therefore, 10 interviews were conducted. It was assumed that performed research and/or collaborations led to impact, and that associate and full professors were able to reflect on their process of generating impact. As a guideline an interview time limit of 30 minutes was maintained, and all interviews were recorded with the Voice Memos application (Apple Inc., 2019) using an iPhone 8 Plus (software version 12.3.2). All interviewees were asked for consent to record the interview prior to the start of the interview and were informed that information discussed in the interview could be used in this study after anonymisation of the data.

At the start of the interview the interviewee was asked to give their interpretation of impact and was asked if they thought that their interpretation of impact was similar to the interpretation of other people at TU Delft. The latter was asked to get insight in their awareness of their interpretation of impact compared to that of others. Next, the interviewee was asked to give an overview of their research lines/projects, and the possible areas of impact for those lines/projects were discussed. This information could be used to determine preliminary focus areas and scales of the interviewees. Subsequently the interviewee was asked to explain what research project/line led to the biggest impact (so far) and the scale of impact was briefly discussed. This impact was discussed in more detail by asking the interviewee how they reached this level of impact. The answers to this question were used to identify possible enablers for generating impact, as it was likely that the reasons given enabled them to gain said level of impact. Finally, they were asked to discuss a research project that did not reach a level of impact they had hoped for, and to identify reason why it did not reach that level. The answers to this question were used to identify possible barriers which hamper generating impact, as it was likely that reasons given did not enable them to reach a higher level of impact.

Since there is a mix of national (Dutch) and international staff members, interviews were conducted in Dutch and English depending on the preferred language of the participant. The protocol for the semi-structured interviews, in both Dutch and English, is included in *Appendix III – Semi-structured interview protocol*.

All interviews were transcribed, in either Dutch or English, at Intelligent Verbatim Transcript level (Weloty Academic Transcription Services, 2015). Intelligent verbatim omits ‘uhms’ and pauses, and slightly improves grammar and interpunctions, and thus improves readability of transcripts. This level of transcription was chosen, because in context of this study ‘what’ is said is considered to be more important than ‘how’ it is said.

A brief look was taken at the coded sub-concepts of 'Area' and 'Scale', but since this is a small sample size, specific group of people in a specific context, the conclusions have limited generalisability. Therefore, these will be discussed briefly.

3.1.2 Concept coding

All transcripts were coded, by the author, using concept coding (Saldana, 2015) in NVivo 12 for the concepts 'Area' and 'Scale' including sub-concepts derived in section 2.2.3. This was also done for the concepts 'Enabler' and 'Barrier', to identify enablers and barriers of impact. The coding tree used for concept coding the transcripts is included in *Appendix IV – Coding Tree Interview Transcripts*.

Enablers and barriers were identified based on answers given to questions that asked for enablers, or barriers, and the overview of indicators for impact areas was used to identify other enablers mentioned during the interview. All fragments of text that were concept-coded as 'Enabler' or 'Barrier' were quoted from the transcript and listed in an overview. Fragments quoted from interviews that were conducted in Dutch were translated to English. It was tried to remain as close to the original meaning of the quote, this was verified two students for the master program Communication Design for Innovation.

3.1.3 Qualitative analysis

All fragments identified as enabler or barrier by concept coding, were further analysed for an overarching theme. Based on overarching themes combinations of enablers and barriers were made. Barriers were transformed from to enablers, following the reasoning 'when you know what hampers something, you can solve it'. This is comparable to using identified 'weaknesses' and 'threats' in a SWOT analysis to minimise and/or avoid them or turn them into opportunities.

3.2 Outcomes

Following the aforementioned protocol, and subsequent concept coding, ten participants were interviewed. The transcript of the interview with Participant 6 is included in *Appendix V – Example Transcript Semi-Structured Interview*, as an example. All transcripts and audio files of the ten performed interviews can be requested at the Department of Science Education & Communication. Based on these interviews a preliminary analysis of the focus areas and scales for biotechnologists, an academic point of view on impact and enablers for impact are discussed below.

3.2.1 Focus areas and scales for biotechnologists

During the interviews the participants were asked what they thought the impact of their current research was, or is going to be, and in which area that impact would be found. These areas were identified via concept-coding 'Area' with sub-concepts based on the 9 areas selected in section 2.2.3. Each participant mentioned that their work would have scientific impact, advancing or contributing to academic knowledge (Table 7). Nine participants mentioned that their research would have environmental impact, mainly aiding in sustainability and the reduction of pollution and climate change, and technological impact, the application of knowledge in an industrial setting. Furthermore, eight participants mentioned that they would have educational impact, mainly in educating a new generation of students, PhDs and post docs. The education of a new generation would subsequently have an impact on society, an area of impact that was mentioned by seven participants. Economic impact, mentioned by five participants, was realised in combination with technological impact, mainly in creating new jobs when applying knowledge in an industrial setting. Impact on health and cultural impact was mentioned five and three times, respectively. Impact on health was related to environmental impact in reducing pollution, but also in the development of medicine. Cultural impact was most often in the form of aiding in the engagement of the public with science and contributing to the public debate considering science. Lastly, one participant mentioned that a possible impact of their findings could lead to the development of policy, i.e. political impact.

Table 7. Mentioned areas of impact in 10 interviews with associate and full professors of the Department of Biotechnology at TU Delft.

Area	# of records mentioned, out of 10
Scientific	10
Environmental	9
Technological	9
Educational	8
Societal	7
Economic	5
Health	5
Cultural	3
Political	1

Interestingly, when comparing the mentioned areas of impact to what was found in literature, educational impact is mentioned more often in interviews than in literature, percentage wise, 80% vs. 16% respectively. Since this study consists of a limited number of interviews within a biased group of participants, and considers a limited amount of literature, no conclusions can be drawn. However, this might give an indication of different priorities, or areas of focus, of researchers compared to those of impact-evaluations, where economic, political and societal impact was found most often.

Relating this to the documents developed by TU Delft, the framework *Impact for a better society* and the Global Engagement Framework, a similar difference in focus areas is observed. Both frameworks focus on technological and societal impact, as do researchers, however researchers also attach a lot of value to educational impact as illustrated by quotes of participants in Quote 1. Furthermore, one participant pointed out that there could be a discrepancy between what researchers see as impact, and the organisation sees as impact (Quote 2).

> *And the first and foremost target of the TU Delft, and of any university, whether it is a university of technology, or a university, is the education of a new generation, of young people…*
>
> *Participant 6*
>
> *Probably, I have more impact on teaching here in the department…*
>
> *Participant 7*
>
> *The most important impact of universities is the education of people*
>
> *Participant 10 **

Quote 1. The importance of educational impact of universities.
* Quote translated from Dutch to English.

> *I think there is a discrepancy on what the researcher sees as impact from what the head of our university or Rector sees as impact.*
>
> *Participant 3*

Quote 2. The discrepancy of what is seen as impact.

Besides areas, scales of impact were also questioned during interviews; and were further concept-coded in sub-concepts of 'Scale' as were selected in section 2.2.3. It must be noted that only in six interviews scales of impact were mentioned. However, when scale was mentioned in context of impact, it was focused on the international level (Table 4). One of the participants even explicitly mentioned it was better to focus on international impact by working on Sustainable Development Goals (Quote 3).

Table 8. Mentioned scales of impact in 10 interviews with associate and full professors of the Department of Biotechnology at TU Delft.

Scale	# of records mentioned, out of 10
International	6
Local	3
Community	1
Nation	1
Region	1
Society	1
Individual	0
Organisation	0

> *Now if we want to make impact, then we can better choose those [Sustainable Development Goals] than smaller regional things.*
>
> *Participant 8 **

Quote 3. A preference for international impact over regional impact.
* Quote was translated from Dutch to English.

3.2.2 An academic's point of view on impact

Since the interviews were semi-structured, several other interesting notions related to impact arose. Two participants, Participant 1 and Participant 9, mentioned that we should be careful, or cautious, about things that immediately receive media attention (Quote 4). In a review published by Lømo (2015) he compared the impact of two studies he was involved in, where it took one study many years to be recognized, while the second study caused immediate sensation, but was now largely forgotten. He ends by stating that "in the long run, discovering something new has greater impact than falsifying a popular hypothesis". This is similar to what Participant 9 stated, disproving that there is no life on Mars is difficult, it will eventually be forgotten.

> *…you can be impactful, but there you need to be 100% sure; things that are discovered on the one day and the next day are in the news, well then, we should be extremely careful.*
>
> *Participant 1*
>
> *You often see this, well I think not at TU Delft, but you often see this in medical research. People quickly go to the press with something that in 10, 15, 20 years could lead to a cancer treatment. Or NASA, who send a yearly press release about possible life on Mars, you could also call all that impact, because they receive a lot of attention, but actually the impact is marginal.*
>
> *Participant 9 **

Quote 4. The difference between media attention and actual impact.
* Quotes translated from Dutch to English

One of the participants explained that it was difficult to completely assess the impact of the performed research, because the main source for the quantification is citation scores (Quote 5). Therefore, within the scientific community the impact was visible, but not beyond that area. This was exemplified by stating that companies could very well use the produced knowledge without leaving a trace. This is due to the fact that it wasn't patented, but public knowledge (also due to the fact that TU Delft wants researchers to publish in open access journals).

> *It's difficult to quantify for us, the impact we really have, we can only measure it really, it's the citations, how many times is your work cited. But … when companies use this knowledge, there is no trace. Because … we don't patent better understanding of how a system is regulated, for instance, you just want everybody to have access to this information, well if a company uses that, there is no patent and you don't know.*
>
> *I mean I only see the impact on the scientific community,*
>
> *Participant 3*

Quote 5. The difficulty for researchers to quantify impact.

Participant 5 raised the question of ownership of responsibility of making an impact (Quote 6); when does generating impact become a responsibility of the organisation and when does it remain with the researcher? A question neither the author, nor the participant could answer.

> *Well you have this position within the university; and you are in fact appointed to inspire people and to build up their expertise and, besides that, to do research with added value, especially within a university of technology, like Delft. But then you also have the responsibility to do that, and this responsibility is often not discussed, but it is true that the impact is looked at. Well it is tried to keep the impact as big as possible, were we often don't connect this to personal profiling, like 'how do you make sure, as an organization, that a researcher also has the possibility to realise an impact'. Or do you expect a researcher to do this by themselves? Where does that responsibility stop and does it become a responsibility of the university, and when does it stay a personal responsibility?*
>
> *Participant 5 **

Quote 6. Does responsibility of generating impact lie with researchers or the organisation.
* Quotes translated from Dutch to English

In order for research to have societal impact, it has to be societally relevant, e.g. that society will benefit from this research. The philosophical question that Participant 6 raised during the interview (Quote 7) was "what is societally relevant?", which leads to the question "who determines what is societally relevant?" and "How do I cope with that as a researcher?".

> *But then it is rather difficult what is societally relevant, because if you look at the topic that is nuclear power, some people think that is the solution to everything, and other people think that's the demon you shouldn't touch.*
>
> *Participant 6*

Quote 7. Issues of determining social relevance.

Finally, Participant 10 highlighted that it is completely fine that not everything works out, and that you should accept that (Quote 8).

> *** Interviewer: Are there things that you've spent a lot of time and effort on which eventually did not reach the place where you had hoped they would go?*
>
> *** Participant 10: Of course, and that is exactly how it should be.*

Quote 8. Not everything needs to have an impact.
* Quote translated from Dutch to English

3.2.3 Enablers and barriers for the generation of impact

Based on concept-coding a total of 54 potential enablers and 22 potential barriers for impact were identified and are shown in tables in *Appendix VI – Potential Enablers and Barriers for Impact*; potential enablers were number as 'E#' and potential barriers were numbered as 'B#'.

Since semi-structured interviews were conducted, and thus participants had more freedom to elaborate on certain topics, a variety of enablers and barriers were mentioned. Participants often mentioned communication and collaborations, together with additional conditions and/or points of attention, awareness for context, and awareness for knowledge gaps and negative aspects. As some themes, like collaborations, were mentioned multiple times, potential enablers and barriers for impact were combined under overarching 'enabler' themes. An example of combining enablers and barriers is presented in Text Box 4.

E4:

That [having a reputation as a scientist] is also a very important aspect yes. I think it is easier if you are, if you have a reputation already.

E6:

…the trust you have in your data…

E13:

…we produce really high-quality results, data, and we are acknowledged for that.

B1:

…you have several hurdles, you need to be known in the scientific community, to prove that there if you have recognized that, then you can start to go forward and to get a larger audience.

Combining E4, E6, E13 and B1 led to:

Have a good reputation as a researcher

Text Box 4. Combining potential enablers and barriers with an overarching 'enabler' theme.

Potential enablers and barriers were combined when possible which led to 21 overarching enablers, of which 16 were based on combinations of enablers and barriers, and 5 were based on individual quotes. An overview of the overarching enablers is given in Table 9. It should be noted that these overarching enablers do not lead to guaranteed success but could help in generating impact.

3.3 Chapter conclusion

This chapter answered RQ3, by semi-structured interviews, concept coding and qualitative analysis.

RQ3 *What are potential enablers and barriers for generating impact?*

Based on concept coding of the transcripts of 10 semi-structured interviews with academic staff members of the Department of Biotechnology, a variety of possible enablers for generating impact and barriers that hamper generating impact were identified. In a qualitative analysis, overarching themes in these enablers and barriers for generating impact were identified. Based on the identified overarching themes possible enablers and barriers were combined to form 15 general possible enablers (Table 9). These enablers do not lead to guaranteed impact but could help in generating impact. Furthermore, some points of attention were noticed which could also help in generating impact, as mentioned by interviewees. These points of attention include be enthusiastic; don't waste time chasing impact; when things are very specific, don't expect a big impact; it takes time before something is known; work with good/the right students/people; and when bringing inventions to the market, protect your results.

Table 9. Overarching enablers for impact based on combinations of enablers and barriers which were identified via semi-structured interviews with staff members of the Department of Biotechnology at TU Delft.

#	Overarching enabler	Based on quotes
1	Communicate properly about the project, and make use of tools, (Twitter, LinkedIn, the communication department of the faculty	E1, E3, E8, E11, E12, E28, E29, B9, B10,
2	Demonstrate the quality and added value/benefit of your work	E2, E5, E13, E20, E38, B17, B19
3	Have a good reputation as a researcher	E4, E6, E13, B1
4	Be an inspiring supervisor, that consider a personal dimension education. (gives people freedom, encourages them)	E7, E9, E51, E52
5	Identify knowledge gaps/problems, and create solutions based on knowledge	E14, E18, E21, E26, (E30), E39,
6	Use your network to be aware of what others are doing, and test your own ideas	E15
7	Collaborate with the right people, be transparent in goals, time lines, recognise different context and re-evaluate continuously	E16, E31, E34, E41, E46, E47, E48, E49, B18, B20
8	Be aware of limitations/negative aspects/resistances, and solve these in your design	E22, E40, B7, B15, B16
9	Be aware of the context for which you are designing, and aware of the context you are in, and be aware this context will change over time	E23, E36, E37, E49, E53, B11, B12, B13, B21
10	Approach a problem from multiple dimensions/disciplines	E24, E25, E32, E35, E44 E45, B8, B14
11	Optimise publishing, know what kind of people could have an interest in your findings, then choose the best suited journal for that audience	E12, E27, E43, B5, B10
12	Make sure the project also works from an economic perspective	E33, B6
13	Be open to ‘coincidental ideas’/serendipity, and recognize the start of possible applicability at an early stage	E44
14	Develop things in parallel with an open mind	E54, B22
15	Research is a two-way process, so be aware of the public interest	B2

4 A tool for mapping impact

This chapter aims to answer the following research question:

RQ4 *What can a tool look like that maps the impact of scientists?*

In order to answer RQ4 a tool that maps the impact of scientists is designed, based on the outcomes of RQ1-RQ3. The outcomes of RQ1-RQ3 were used to develop design requirements, which were translated into a design brief, prioritizing requirements. Detailed descriptions of the methods used are given in section 4.1. Based on this design brief a preliminary design for an impact mapping tool is made, since this is not the main focus of this thesis. Furthermore, a workshop is organised to test this preliminary design. The preliminary design of an impact mapping tool and the outcomes of the workshop are discussed in section 4.2. This is followed by an answer to RQ4 in the concluding section 4.3. A schematic overview of methods used and outcomes are shown in Figure 8.

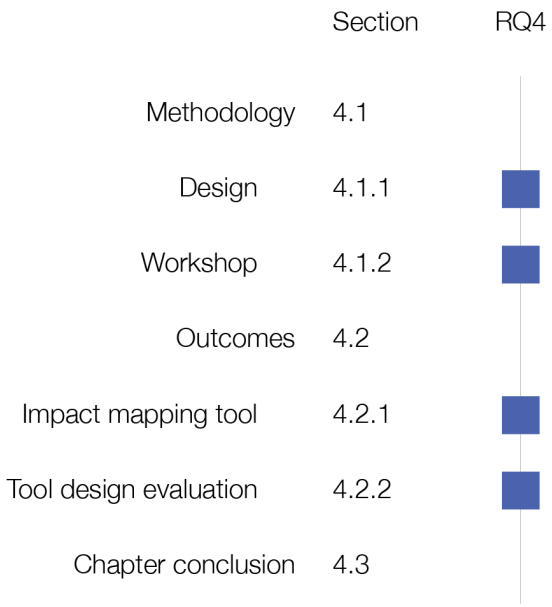

Figure 8. Schematic overview of the structure of Chapter 4, including methods used, outcomes and chapter conclusion.

4.1 Methodology

In order to design a tool that maps the impact of scientists, design requirements were set, which were subsequently prioritized in the design brief. The design requirements were based on the main findings of Chapter 2 and 3 which were considered important for mapping impact. Based on the design brief a design proposal for a tool that maps impact was made, following multiple iterations. Furthermore, an analogy was used to further improve the design. Finally, a workshop is organised to test the impact mapping tool design proposal.

4.1.1 Design

The tool design was based on design requirements and design brief, both set by the author, which are further explained in the following sections.

4.1.1.1 Design requirements

The design requirements followed from the outcomes of Chapter 2 and 3. Main outcomes that were considered of importance to impact mapping were selected as requirements for a tool that maps

impact. Furthermore, requirements for the ‘look and feel’ of such a tool were formulated. Inspiration for these requirements was taken from an interview with Meike Geertsma, HR manager at the Faculty of Applied Sciences, TU Delft, who had organised workshops considering ‘impact’ in the past.

4.1.1.2 Design brief

Based on the design requirements a design brief was made by the author. The design requirements were prioritized according to the following priorities: must have, should have and nice to have.

4.1.1.3 Design proposal

Following the design brief, a design proposal for a tool for mapping impact was made. This was done by small brainstorm sessions of the author of this thesis with fellow students of the Communication Design for Innovation master. These brainstorm sessions aimed to combine must haves, should haves and nice to haves in a design proposal.

4.1.1.4 Analogy

The developed design proposal was compared to an existing mapping tool, unrelated to impact, which resulted in further insights in the use of the impact mapping tool. By using an analogy characteristics of the analogous object could be transferred to the initial subject, in this case the impact mapping tool.

4.1.2 Workshop

The developed design proposal for an impact mapping tool was tested with a group of four students of the Communication Design for Innovation (CDfI) master programme, exploring the possible impact of their work. Most students follow a second master programme, different from CDfI, and combine both master programmes in their thesis, and all study a different subject in their thesis. Therefore, it is expected that their work will have differences in impact, which would allow for discussion on differences between participants.

The workshop followed the developed workflow (section 4.2.1.3.1), taking approximately 20 minutes for each part, followed by an evaluation of the tool. The following questions were asked for the evaluation of the tool:

- Did the awareness of the impact of your research increase by using the tool?
- Was anything unclear in the ‘assignments’, and if so, what was unclear and why?
- Did you miss anything, and if so, what did you miss and why?
- Is the tool easy to understand, and is the visualisation easy to interpret?
- Any other suggestions?

A result of this workshop and evaluation, was insight in the workings of the tool in a practical setting, and recommendations for improvements for a next iteration.

4.2 Outcomes

4.2.1 Impact mapping tool

4.2.1.1 Design requirements

The aim of the tool is to map the impact of scientists, hereto requirements for such a tool for were set based on the outcomes of previous chapters. In Chapter 2 interpretations of impact were analysed for the presence of themes, which were referred to as *Bias, Demonstrable, Area, Scale* and *Directness*. Furthermore, areas and scales of impact were selected based on their occurrence in literature, and indicators for impact per area were identified. From this a requirement for a tool that maps impact would be the incorporation of the nine selected areas (scientific, economic, technological, societal, cultural, political, environmental, health and education) and the eight scales (individual, local, regional, community, organisation, society, nation and international). This incorporation is required, as it would allow for actual mapping of impact within areas and scales and provide insight in where scientists have impact. Since there is a relation between areas of impact and scales of impact, another requirement is to link areas and scales in an impact mapping tool. Additionally, a requirement would be the consideration of *Bias*, *Demonstrable* and *Directness* within the tool. These three themes, analysed in Chapter 2, are of importance to distinguish between 'types' of impact. This would also enhance the awareness of scientists for the possibility of impact to be either positive or negative, either demonstrable or non-demonstrable, and either direct or indirect. Furthermore, a requirement is the incorporation of the indicators of impact per area. These indicators could help scientists place the impact of themselves or their research in certain areas, but also serve as an inspiration for achieving impact in other areas.

In Chapter 3 semi-structured interviews with academic staff members of the Department of Biotechnology were conducted, which led to the identification of 15 possible enablers of impact. These enablers could serve as a means to enable scientists to possibly achieve impact in another area, or on another scale. This surpasses the aim of the tool, to map the impact of scientists, but is a nice extra for such a tool, and therefore incorporation of possible enablers is an additional requirement.

The 'look and feel' of such a tool should facilitate an easy overview of the impact of a research project or scientists. Therefore, an additional requirement is that it should be easy to understand. Furthermore, an interview with Meike Geertsma, in which she talked about the set-up of a workshop about impact, she organised in the past, served as inspiration for further requirements. Here she explained that the workshop she organised facilitated dialogue between scientists, and helped researchers look at their research projects from a different perspective. This was found to be helpful, and therefore this is another requirement for an impact mapping tool for scientists.

All design requirements are listed in Text Box 5.

4.2.1.2 Design brief

The requirements mentioned in the design requirements were prioritised according to 'must haves', 'should haves' and 'nice to haves' to create a design brief. Since the aim of the tool is to map impact of scientists, the must haves include the incorporation of areas of impact and scales of impact; the combination of areas and scales; the indicators of impact. Furthermore, a must have is that it should be easy to understand and the facilitation of dialogue.

Since the raising of awareness for the kinds of impact, i.e. positive or negative impact, is not the aim of this tool, these are prioritised as must haves. Finally, the incorporation possible enablers of impact are prioritised as a 'nice to have' since they surpass the goal of mapping impact. The prioritisation of design requirements is shown in Text Box 6.

Incorporation of the 9 areas of impact

Incorporation of the 8 scales of impact

Combines areas of impact with scales of impact

Consideration of both positive and negative impact

Consideration of both demonstrable and non-demonstrable impact

Consideration of both direct and indirect impact

Incorporation of indicators of impact per area

Incorporation of the possible enablers of impact

Easy to understand

Facilitation of dialogue

Text Box 5. Design requirements for an impact mapping tool

Must haves

Incorporation of the 9 areas of impact

Incorporation of the 8 scales of impact

Combines areas of impact with scales of impact

Incorporation of indicators of impact per area

Easy to understand

Facilitation of dialogue

Should haves

Consideration of both positive and negative impact

Consideration of both demonstrable and non-demonstrable impact

Consideration of both direct and indirect impact

Nice to haves

Incorporation of the possible enablers of impact

Text Box 6. Design brief for an impact mapping tool for scientists

4.2.1.3 Design proposal

Based on the design brief for an impact mapping tool for scientists (Text Box 6) an initial concept was made, in the form of a table, which included most must haves, except for the facilitation of dialogue and the incorporation of indicators of impact per area. A table was chosen as a concept since it clearly links to parameters with each other, like the areas and scales of impact. Furthermore, it is easy to understand and gives a comprehensible overview of where impact is found. This concept was iterated to a design proposal for an impact mapping tool. The design iterations from the initial concept to the presented design proposal are included in *Appendix VII – Impact mapping tool design iterations*.

In this tool the impact of a central object – the scientist or research project – should be visualised, therefore it was decided to place this object in the centre. From this centre the impact quite literally radiates outward, following a logical order of organisational scales, i.e. the scales of impact. Hereto the smallest scale on which impact is found is the individual, and the largest is on an international level. By arranging the areas of impact around this central object, the impact per area could be shown. For this, icons were designed which symbolise the areas of impact, shown in Figure 9. An atom with electron shells was chosen as a symbol for scientific area, a gear was chosen for the technological area, and stacks of coins were chosen for the economic area. For the societal area a group of people was chosen, for the environmental area trees were chosen and for health a person with a drawn in heart. Furthermore, for the political area a person behind a lectern was chosen and a square academic cap was chosen for education. All aforementioned icons resonate well as a schematic representation of an area. Since culture does not have a defined symbol a lotus flower was chosen, a universally applicable icon.

A workflow was designed for the usage of the tool, in the form of a workshop. The design proposal for an impact mapping tool is presented in Figure 10. The structure of the workshop is explained in section 4.2.1.3.1.

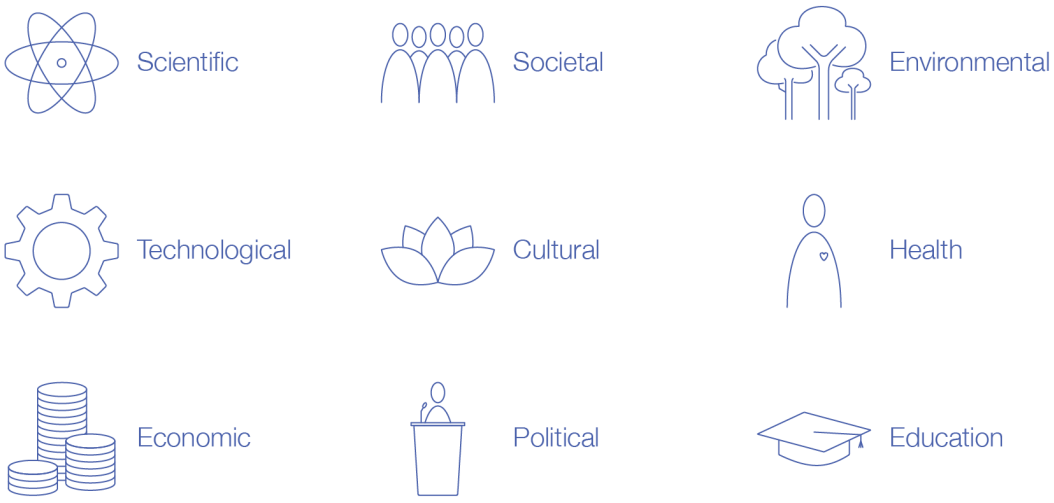

Figure 9. Icons for areas of impact.

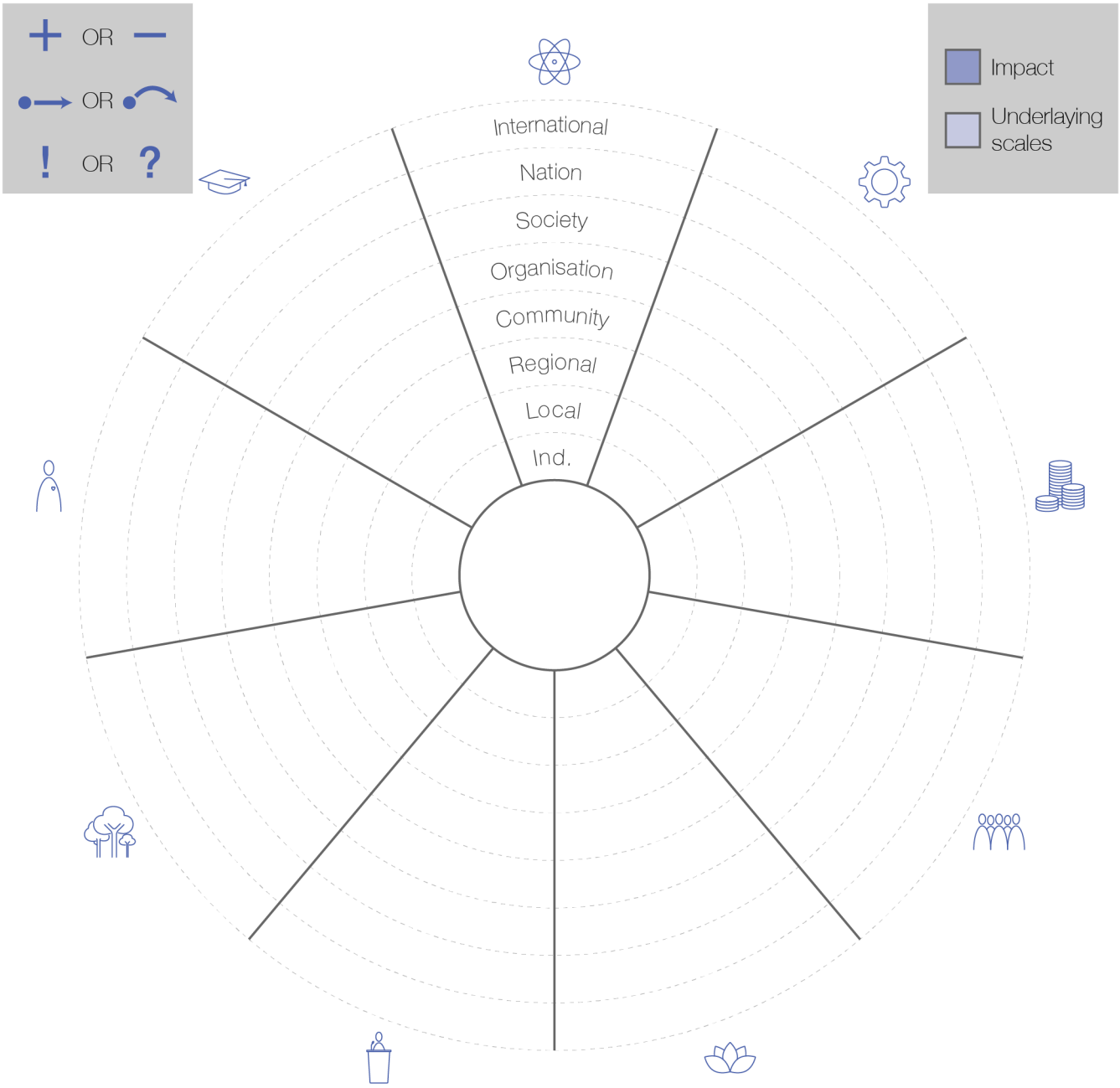

Figure 10. Design proposal for an impact mapping tool for scientists.

The design proposal places the object of interests in the centre – either the scientist or the research project – and is surrounded by areas of impact. This visualisation is inspired by a radar plot, commonly used to visualise data. Each shape enclosed by dashed lines symbolised the impact of the central object on a certain level of scale within one of the nine defined areas of impact. By shading all shapes corresponding to where impact is found a comprehensible overview of where impact is found arises. However, when impact is found on a certain level of scale, it is not automatically found in all underlying scales, therefore a visual distinction is made by using two colours for shading shapes. A filled-out example is presented in Figure 11.

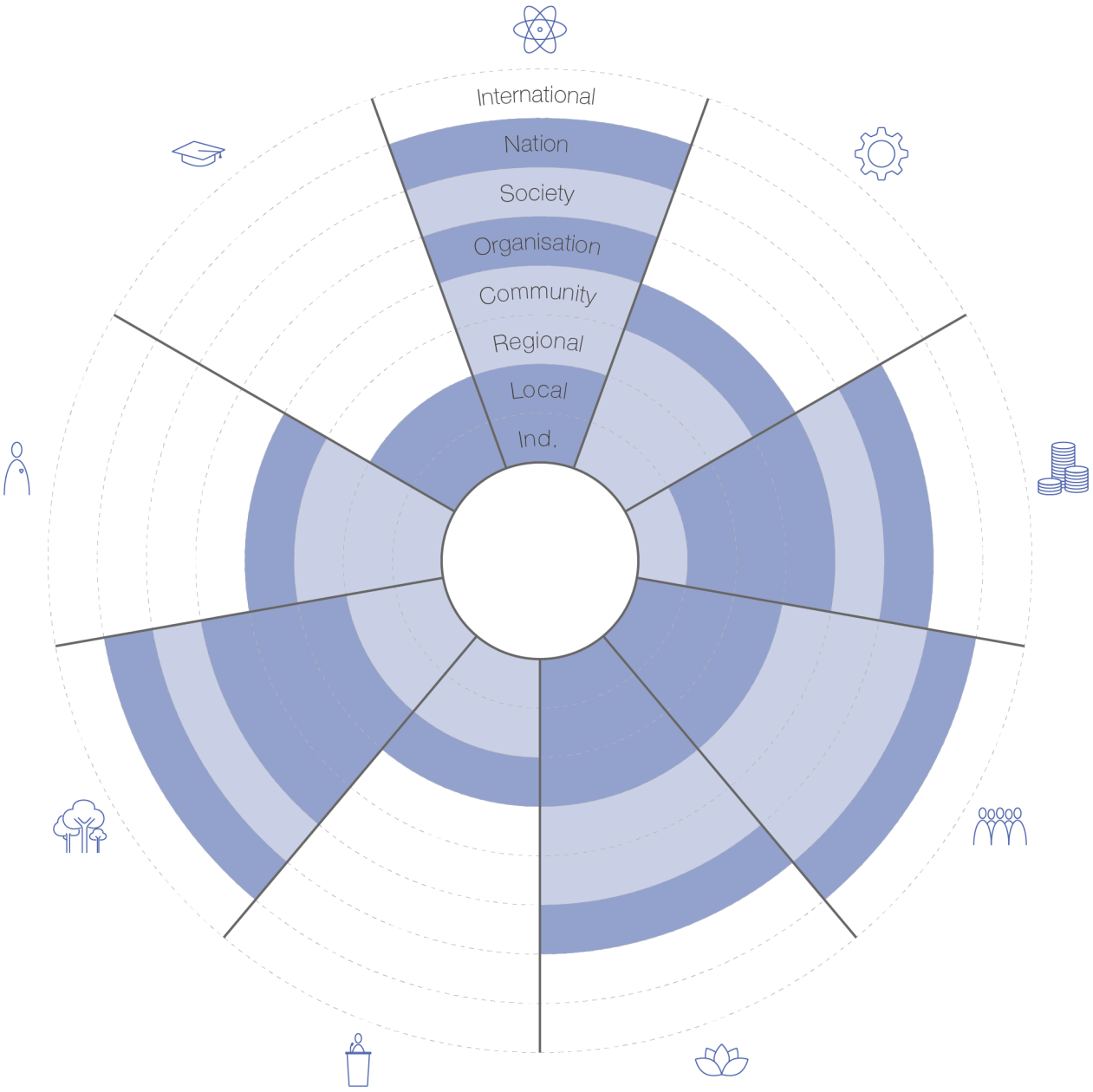

Figure 11. A donut design of the radar plot. In the centre the name of the person/project in consideration can be written. Dark-coloured areas represent impact; light-coloured areas represent possible impact in underlying levels of impact.

In the upper left corner of the design proposal a box is shown with 6 symbols, representing the considerations mentioned as a ‘should have’ in the design brief. For each of the shaded shapes – impact of the central object – these symbols should be chosen when filling out the overview. Hereto, the participant filling out the overview must indicate if the impact was either positive or negative, either direct or indirect and either demonstrable or non-demonstrable. This raises awareness for the types of impact. Symbols for the type of impact are shown in Figure 12 and an example of a filled-out shape with symbol indications is presented in Figure 13.

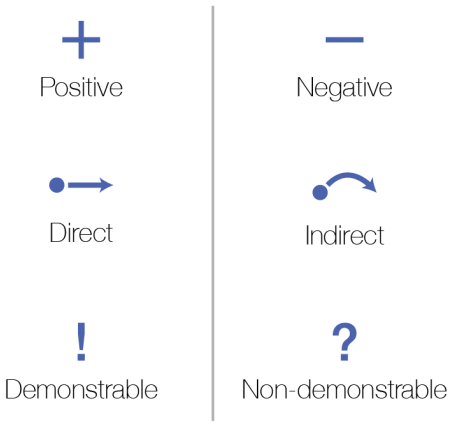

Figure 12. Symbols for positive and negative impact, direct and indirect impact and demonstrable and non-demonstrable impact.

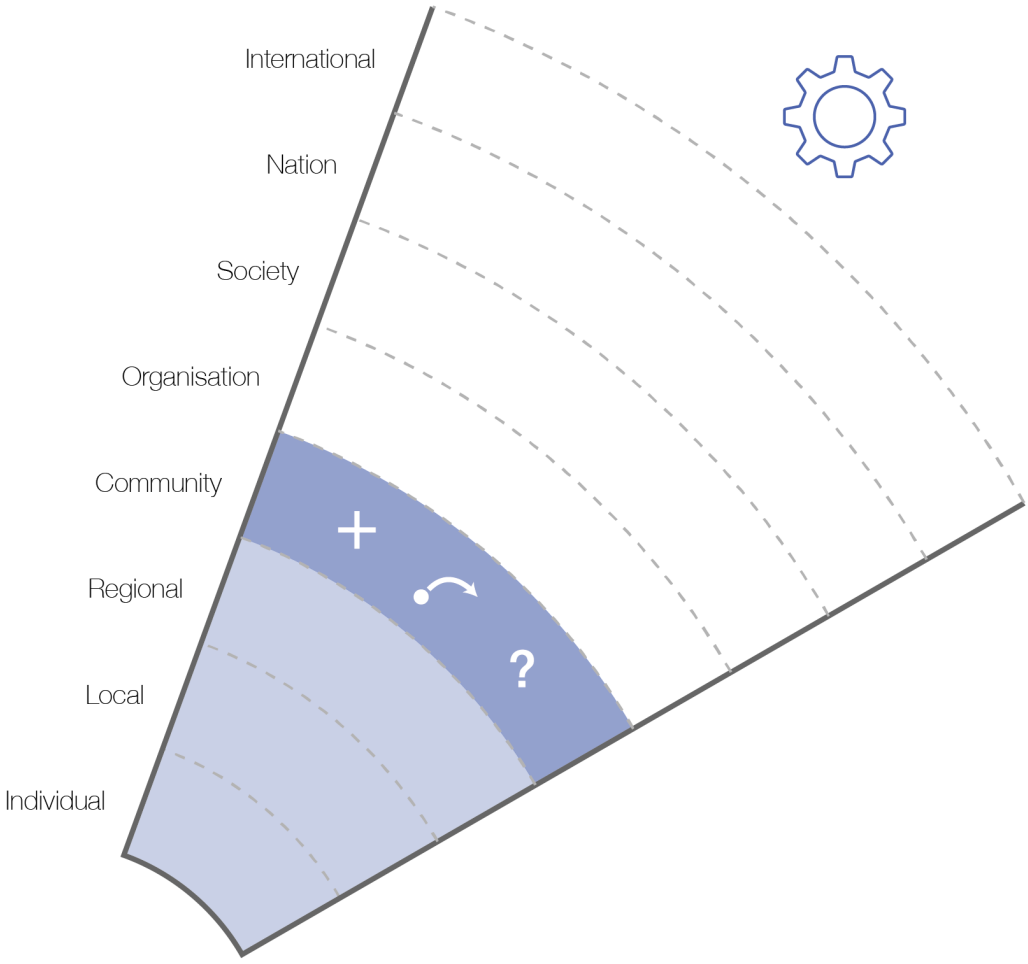

Figure 13. Example of positive, indirect, non-demonstrable technologic impact on a community level.

4.2.1.3.1 Workflow for tool usage

The workflow designed for the usage of the tool is in the form of a workshop, an “impact mapping workshop”. This workshop consists of three parts. Part I of this workshop will be on an individual basis, parts II and III will be done in duos. First the person guiding the workshop will explain what the tool is, which areas and types of impact there are. Then in Part I, the participant is asked to fill out the overview by answering the following questions: “In what areas does your research have impact?” and “On what scales does your research have impact?”. Furthermore, the participant needs to answer three short questions pertaining to the types of impact per filled-out impact, namely: “Is this positive impact?”, “Is this direct impact?” and “Is this demonstrable impact?”. Afterwards, the participant is given the overview of indicators of impact per area and is asked to reconsider their filled-out impact and possibly missed impact. Hereto the following question is asked: “Using the indicators of impact per area, can you identify more areas of impact?” with follow-up question: “If yes, what/which impact(s) did you first miss? Can you think of a reason why?”. The answer to this question sheds light on why they missed a certain impact, either because they were unaware of the area of impact or that they value that impact less.

In the next part, Part II, participants are asked to form duos and are asked to briefly explain what their research (project) entails, so that partners have a basic understanding of each other’s work. Next duos are asked to compare their results from filling out their overview, answering the following questions: “What are the differences between your and your partners areas of impact when looking at the overview, and where do those differences come from?”. This will help in awareness of the differences of focus areas of impact per research project; partnering with a participant from another field will probably yield the most interesting discussion. Next partners are asked to think of other impact(s) for their partner. The fresh perspective of a partner (from another field) might yield new insights for impact of the research.

Finally, in Part III duos are asked to brainstorm/briefly discuss how to take the current impact to the next level. For this they are supplied with the possible enablers of impact, categorised per area, as shown on page 51. The workshop will take about 60 minutes, approximately 20 minutes per part. The full structure of the impact mapping workshop is presented in Text Box 7.

Impact workshop

Introduction, explaining the tool, the areas and scales, and types of impact

Part Ia - Individual

Fill out the radar plot by answering the following questions:

In what areas does your research have impact? And on what scales? Is this positive impact? Is this direct impact? Is this demonstrable impact?

Part Ib - Individual

When given the indicators, answer the following questions:

Using the indicators of impact per area, can you find more areas of impact?

If yes, what/which impact(s) did you first miss? Can you think of a reason why?

Part II – In duos

Explain what your research entails to your partner.

Answer and discuss the following questions:

What are the differences between your and your partners areas of impact when looking at the overview, and where do those differences come from?

Could you think of other impact(s) for your partner?

Part III – In duos

Use the general and area-specific enablers.

Could you think of a way to take an impact to a next level of scale?

Text Box 7. Structure of impact mapping workshop

Communicate properly about the project, and make use of tools, (Twitter, LinkedIn, the communication department of the faculty)

Identify knowledge gaps/problems, and create solutions based on knowledge

Use your network to be aware of what others are doing, and test your own ideas

Collaborate with the right people, be transparent in goals, time lines, recognise different context and re-evaluate continuously

Be aware of the context for which you are designing, and be aware of the context you are in, and that this will change over time

Approach a problem from multiple dimensions/disciplines

Demonstrate the quality and added value/benefit of your work

Have a good reputation as a researcher

Be aware of limitations/negative aspects/resistances, and solve these in your design

Optimise publishing, know what kind of people could have an interest in your findings, then choose the best suited journal for that audience

Be open to ‘coincidental ideas’/serendipity, and recognize the start of possible applicability at an early stage

Research is a two-way process, so be aware of the public interest

Demonstrate the quality and added value/benefit of your work

Have a good reputation as a researcher

Be aware of limitations/negative aspects/resistances, and solve these in your design

Be open to ‘coincidental ideas’/serendipity, and recognize the start of possible applicability at an early stage

Demonstrate the quality and added value/benefit of your work

Develop things in parallel with an open mind

Research is a two-way process, so be aware of the public interest

Research is a two-way process, so be aware of the public interest

Be an inspiring supervisor, that considers a personal dimension education. (gives people freedom, encourages them)

4.2.1.4 Analogy

From the design proposal of the tool, and even the name of the mapping method used (a radar plot), it is only a small step to an actual radar. In this section an analogy between the impact mapping tool and a radar is used to get more insight in the developed tool.

4.2.1.4.1 Tool

The impact mapping tool requires people to identify their organisational level of impact in a defined set of areas. For each of the mapped impacts it is required to indicate if this considers positive or negative impact, demonstrable or non-demonstrable impact, and direct and indirect impact, and show this with symbols. Within each area multiple impacts can be found, on different levels of scale. The mapping tool does not differentiate between importance of levels of impact, since impact on an individual level could be as important as impact on an international level.

4.2.1.4.2 Radar

Radar is a technology that is used as a detection system to determine the range, angle, or velocity of objects relative to a defined point. It uses radio waves, and is able to detect terrain, aircraft, ships, and weather formations, among other things. Similar to the tool, the detected objects are often mapped in a circular plot, hence the name radar plot. Nowadays, with newer technology, the mapping is no longer restricted to circles, and the characteristic bright green-ish colour.

4.2.1.4.3 Insights

The impact mapping tool can be compared to the use of radar to detect stationary surrounding objects relative to a stationary point. The detected objects are the equivalent of the mapped impact, the only difference being that radar does not have ‘dedicated’ areas in its map for certain objects.

When radar is used to detect moving objects around a stationary object or is used to detect stationary objects around a moving object, it is constantly comparing the relative position between the two points. The speed and relative position of the detected object is important to avoid collision, avoiding impact, and therefore objects entering the map are of importance. This can be roughly translated to the one of the enablers, namely: “be aware of the context for which you are designing, and the context you are in, and be aware this context will change over time”. Changes in the outer levels of scale (national and international), could also have an impact on the project/person in consideration. An international focus on your research subject could open up possibilities for impact on greater levels of scale than before; dissolving interest in your research subject could also limit your impact. So, besides the impact on a field, a field can have impact on you/your project as well.

Furthermore, using this analogy of a radar, resulted in the name for the tool: **The Impact Radar**.

4.2.2 Design proposal evaluation

During a workshop, the design proposal for the Impact Radar was tested with four students of the master programme Communication Design for Innovation, following the described workflow of Text Box 7. While participants were using the tool, notes were taken of immediate feedback, the workshop was closed with a brief evaluation of the tool.

First of all, using the tool did give an overview of the impact of each considered study, and increased the awareness of that impact, as was confirmed by the participants. The indicators were found to be very useful and led to awareness for previously unconsidered areas of impact. It was noted that the final step, Part III, is a more diverging step, which is a strange end to the use of this tool. An extra step, making use of the supplied enablers, could be to create a focus on a specific impact-area of importance. It was mentioned that focussing on a certain impact-area could also easily lead to the development of a communication strategy. This also seemed more fitting than asking the participants to take their impact within a specific area to a next level of scale, as it was explained that all impact is equal.

Secondly, there was slight confusion on how to interpret the various scales of the Impact Radar. The scales ‘organisation’, ‘community’ and ‘society’ did not fit within the other five defined scales was mentioned by the participants. However, upon further discussion, it was also deemed that those scales, maybe except for society, were important; your work could have impact within the community that specialises in that subject. No alternative has been thought of to solve this problem. During Part II and III, which were carried out in duos, interesting discussions took place, discussing mostly why certain impacts were not shaded.

A major point of attention should be the introduction of the tool itself, which should mainly highlight why it is important to be aware of the impact of your research and should introduce all areas and scales of impact briefly. Furthermore, it was mentioned that besides thinking of the impact(s) your research has, also thinking about the types of impact was a bit much. It was also mentioned that it was hard to separate indirect and direct impact from demonstrable and non-demonstrable. Participants said that the two types seemed to connect in a similar fashion as was thought by the author, and as was investigated in Chapter 2. In this case an example would help to explain the difference. One participant thought of an example that would illustrate this well: a review paper that led to new insights. In that example cited papers have demonstrable impact as well as indirect impact, since it is hard to say what specifically led to new insights.

In addition, thinking about negative impact was found to be difficult. Participants tended to mainly think about the positive impact of their research. A suggestion was given to divide thinking about positive and negative impact, by first filling out all impact, and then asking participants to consider if their research had any negative impact. Hereto, ethical dilemmas could be referred to, since in most of those cases there is a party that experiences something as negative.

Furthermore, it was noted that not all scales were of importance within each area of impact. However, since not all of them have to be filled out, this is not a problem. It could be underlined more that that is not a requirement. Additionally, printing the Impact Radar on A4 is a bit too small to fit in everything, especially if things change; A3 would be a better size. Other remarks included that the symbol for health is maybe a bit unclear when it is printed on a small sized paper, and that the underlying levels of scale do not have any additional value at this moment.

4.3 Chapter conclusion

This chapter aimed to answer the following research question:

RQ4 *What can a tool look like that maps the impact of scientists?*

Hereto, design requirements, design brief and a design proposal were developed. It is recognized that the design presented in this chapter is one of the possibilities to map the impact of scientists. Based on the design brief, brainstorm sessions and ideas of the author, this design proposal was made. Upon evaluation of the design proposal with fellow students, it can be said that the design did provide an overview of the impact of research and raise awareness for this impact. Therefore, it can be concluded that this is a suitable design for a tool that maps impact, however it does need further development before it could be used as a tool to generate impact.

5 Discussion

The goal of this study was to help researchers at TU Delft get more awareness of the impact of their research. Hereto, an exploratory study was performed to identify interpretations of 'impact' in literature, to identify possible enablers and barriers in the generating impact and to make a design proposal for an impact mapping tool. The exploratory approach was used since it aligns best with the research goal. Literature mainly describes the use of case studies to investigate the impact of a specific system or product, like *Assessing the impact of health research on health policies: A study of the Dodowa Health Research Centre, Ghana* by Escribano-Ferrer, Webster, & Gyapong (2017). However, all these separate studies contribute to the problem, as formulated in the problem statement; it leads to the absence of consensus of the interpretation of 'impact'. Identifying the current interpretations of 'impact' mentioned in literature is a first step towards forming consensus on the interpretation of 'impact'. Therefore, an exploratory approach was chosen, to identify, or map, the range of possible interpretations of 'impact'. By further analysing these found interpretations of 'impact', commonalities were identified, which could be used as guidelines to form consensus.

This study further aimed to give insights into where impact is found, by creating an overview of the areas and scales of impact. This would make easier for researchers to communicate about their impact in funding requests or research evaluations. Besides, such an overview could also be used as a guideline for the evaluation of funding requests or research evaluations. Furthermore, it aimed to give insight in how to operationalise the generation of impact. In the following sections these aims are further discussed.

5.1 Provide an overview of impact for funding

In order to create an overview of impact of research, an exploratory literature review was performed on 'impact'. Subsequently this led to the formulation of design requirements for a tool that gives insight in the impact of scientists. To identify the range of interpretations of 'impact, a systematic literature review (SLR) was performed. This study focused on the interpretations of 'impact' present in peer-reviewed literature, excluding records that relate to metrics. Based on this review, and consequent encoding and concept coding of found interpretations, guidelines for a general interpretation of 'impact' were derived. Furthermore, areas and scales of impact were identified, which allow for creating an overview of 'locations' were impact is found.

A decision was made, by the author, to exclude grey literature and metric-related studies, due to time constraints and to limit the amount of records to process. It was also decided by the author, in view of time, that the selection of records per processing step was performed by the author itself. This could alternatively be performed by asking others to select papers following inclusion and exclusion criteria, subsequently including records that were selected by multiple individuals. The first inclusion criterium set was "based on the phrasing of the title and the context", which relates to interpretation of text. Since interpretation is rather subjective, it is not unlikely that results could differ between individuals, which could have influenced the results. However, it is not expected this would lead to major changes in the final outcomes of this study. Furthermore, including metric-related studies – so setting other inclusion criteria – would probably not have changed the outcomes described in Chapter 2. However, they could have provided more insight in the factors that help in generating impact, so they could have influenced the outcomes described in Chapter 3. Contrary, the inclusion of grey literature could have changed the outcomes described in Chapter 2. This was tried to be avoided by including a supplementary data set of Alla et al. (2017), which performed a similar SLR which included grey literature. It is recommended however, to perform a systematic literature review like Alla et al. performed in a wider context rather than focussed on health policy. This would give a wider scope of the possible interpretations of 'impact', as compared to this study.

Besides the identification interpretations of ‘impact’, this study also identified areas and scales of impact. Although this study focused on the areas and scales of impact, other dimensions of impact were also observed in literature and mentioned by interviewee’s, like a time-aspect to impact and a variety of words to describe ‘impact’. During one of the interviews, a participant mentioned that “it takes time before something is known”, as impact could be generated in a short, medium or longer amount of time. This could be an interesting addition to further develop the design proposal for an impact mapping tool. First of all, this would require further research on the aspect of time in generating impact, either by further exploration of literature found in this study, a literature review on the subject specifically or by exploring the subject during interviews. The time-aspect could be easily embedded in the current design proposal, by using a heat map-like colour coding for short-, medium- and long-term impact. Furthermore, this study also identified indicators of impact per area of impact. It was noticed that most indicators found relate to the scientific, political and health area, and little were found that relate to the cultural, societal and environmental area. Further research could identify more indicators for these areas, if that was deemed necessary.

The design proposal for the Impact Radar developed here was evaluated with other CDfI students who possibly had a bias, since they were exposed to the research and often participated in discussion of research outcomes. The bias could be expressed in preliminary knowledge on how to use the Impact Radar, or presumptions on the types of impact. Furthermore, since the subject impact was discussed multiple times during conversations with fellow students, it is possible that they had prior knowledge, which led to more awareness, of impact. However, evaluation of the Impact Radar did lead to an overview of the impact of their research and raised awareness of the various types of impact, as they confirmed. The tool design is not finalised yet, but it does provide a good basis for further development; this study focussed on a design proposal due to time constraints. After a next iteration it is recommended to test this design proposal with faculty members of TU Delft to further develop the Impact Radar. In this next iteration a focus should be on the final part of the workshop, which should be used as a converging step.

Throughout this study the word ‘interpretation’ was used deliberately when talking about how different studies or people described impact, instead of using the word ‘definition’. It was chosen to use the word interpretation, since all studies describe the same concept – impact – but interpret it differently. However, the word ‘interpretation’ still gives the impression that this ‘definition’ of ‘impact’ is open to change. Contrastingly, the word ‘definition’ gives the impression of a more permanent way of describing impact. Using the word ‘interpretation’ feels counterintuitive to the observation stated in the problem statement “how can we expect people to work with the principle of ‘impact’, when there is no consensus on the interpretation?”. Admittedly, using the word ‘interpretation’ would only cause more disagreement over the definition of the word ‘impact’, however considering the exploratory context of this study this seemed appropriate. Consequently, TU Delft has also not given a definition of impact (so far), but it would benefit TU Delft when a clear definition was provided. The definition of impact presented in this study, together with the identified areas and scales, would serve as a good basis for researchers to grasp what impact entails. Regardless of the definition presented in this study, it is recommended that the university provides clarity on the concept of impact, if they want people to use it.

5.1.1 Generalisability

The outcomes of this research, pertaining to creating an overview of impact of scientists, or research, are widely generalisable. Since it considers nine different areas of impact, the design proposal would be suited for any type of science, with each type of science having a predominant area for impact, i.e. political science in the political area and social science in the societal area. Moreover, each research project, irrespective of their scientific field, should be able to point out the impact, therefore this overview would be useful for all scientists.

5.1.2 Potential application

The design proposal for the Impact Radar is focussed on mapping current impact, however the tool could also be used prior to the start of a project to help visualise were people hope to have impact and create a vision. This could potentially lead to a (communication) strategy. Likewise, the Impact Radar could be used by researchers to identify what kind of impact they are 'lacking' at the moment. Although it is not the goal to achieve impact in every defined area, it might be interesting to explore the areas of impact which suit the research best. The Impact Radar could similarly be used to decide which are of impact a researchers should/could focus on.

Furthermore, using the Impact Radar to track the impact of a person/project over time, by periodically filling it out, could give insights in on what time scales impact is generated, and in which areas and scales. It is currently not possible to predict impact, but by monitoring impact more insights can be gathered for the process of generating impact. At this moment it is only possible to reflect on generated impact, but there is no uniform data available to draw conclusions from. Therefore, starting with a standardised monitoring method, like the proposed Impact Radar, would help in further unravelling the process of generating impact.

Finally, this study addresses issues concerning impact, but does not solve them. However, using the overview of the impact that the Impact Radar provides could be used as a basis to develop guidelines for funding requests or research evaluations. Via this overview the applicant can structure her/his impact more easily, similarly, a reviewing committee can use the overview to evaluate how well this aligns with their objectives/vision. Therefore, the Impact Radar could be used to start a more structured way of evaluating research or funding requests, which would lead to more transparency in the process.

5.2 Operationalising impact generation

In order to get insight in how to operationalise the generation of impact enablers and barriers of impact were explored, this was done by performing semi-structured interviews. Hereto interviews with academic staff of the Department of Biotechnology, TU Delft, were conducted. The group of participants is mainly active in the scientific/fundamental and applicated areas of biotechnology research and was therefore biased to present enablers for those areas; cultural and political impact was barely discussed. This is also visible in the further categorisation of enablers, as was done for the design proposal elaborated in Chapter 4. This was done by the author by interpreting how suitable each enabler was for each area of impact. In follow-up research this could be further explored, by asking for specific enablers within each area of impact.

Further, performing interviews with staff members from different faculties would likely have yielded other enablers. Broadening the scope of participants would also shed light on the focus areas of impact of the staff of TU Delft, as it would have more statistical power due to a bigger sample size. Besides, it is not hard to imagine that the faculty of Architecture has a bigger focus on societal and cultural impact, while the faculty of Technology, Policy and Management is more focused on the political area. Further comparison to the defined focus in the *Global framework for impact* would show how the focus areas of the management of TU Delft matches those of the people actually performing the research. In this the management of TU Delft should facilitate the current research, and thus current focus areas, and not force researchers in a certain direction.

The approach used for finding these enablers was based on asking researchers to reflect on their biggest impact to date and think of elements that made it possible for them to attain that level of impact. This required a step of deduction, to extract the actual enablers from the answers of the participant. This step of deduction was carried out by the author; however, it is expected that others derive at the same enablers when performing this step. Further, by asking for the biggest impact to date other impacts, like on smaller levels of scale, could have been overlooked, which could potentially have other enablers. The majority of enablers found in this study were derived from international impact but can be applied to other levels of scale as well. The list of enablers is far from complete and it is recommended to conduct further interviews with academic staff of other faculties to expand the list of enablers. Additionally, interviews could be conducted with people that operate in one of the nine mentioned areas, to identify enablers from their perspective. This could also lead to connecting certain enablers to specific areas of impact, which would make it possible to further focus on a specific impact.

5.2.1 Generalisability

Although the interviews were conducted with staff members of the Department of Biotechnology, TU Delft, the results are generalisable within the applied scientific community; 'Collaborating with the right person' is irrespective of a certain field and could be applied by anyone. This limited generalisability also relates to the context of research performed at TU Delft, as that is an applied setting by nature.

5.3 Contribution to the field

This study contributes to the field of Science Communication as a first step towards starting the conversation about research impact. Since the subject of impact concerns many, especially in an academic setting as TU Delft, it is important to communicate unambiguously about the subject. This conversation should therefore also include the researchers themselves, as they are the ones of which it is expected to generate impact. This conversation should also happen on a national level, with a priority to developed guidelines for the evaluation of funding requests.

Further, looking at the current focus on impact itself, the author agrees with a quote from Participant 10, who stated: "that [an invention not reaching a certain impact] is exactly how it should be". There is a chase for having impact, which might actually interfere with how we, as scientists, perform research. With funding being related to impact more and more, it is possible that a focus arises for research with big impact. This seems contradictory to why people chose research in the first place, based on their curiosity. Impact should be a by-product of this. Research should aim for impact, but that should come second to performing high quality research itself.

6 Conclusion

This study aimed to answer the following main research question:

MQ *How can a tool give scientists awareness of their impact?*

To answer this main question, multiple sub research questions were formulated. First a deeper understanding of the concept of 'impact' was sought out in literature, by performing a systematic literature review. Further analysis of the found literature, led to an answer for RQ1 and RQ2. Next semi-structured interviews were conducted to explore the enablers of generating impact, which led to an answer for RQ3. Outcomes of RQ1 – RQ3 were used to develop a design brief, which led to a design proposal for an impact mapping tool, answering RQ4. All research questions are shown below, including brief answers.

RQ1 *What can or may impact entail based on literature and how can this lead to a general interpretation of 'impact'?*

Based on found interpretations of impact five themes were identified that entail impact in literature. These are *Bias, Demonstrable, Area, Scale* and *Directness*. Furthermore, nine areas of impact were selected were impact may be found, namely: scientific, technological, economic, societal, cultural, political, environmental, health and education. Additionally, eight levels of scale were selected were impact may be found, namely on the level of an individual, local, region, community, organisation, nation, international, and/or society. Finally, a general interpretation of 'impact' was derived following guidelines based on previous analysis as:

> *Research impact is a direct or indirect influence of research outcomes*

RQ2 *What are possible indicators for impact by scientists?*

Based on literature found via the systematic literature review, indicators of impact were listed per selected area of impact. An overview of these indicators is provided in Table 6.

RQ3 *What are potential enablers and barriers for generating impact?*

Via semi-structured interviews potential enablers and barriers for the generation of impact were identified. These were combined in an overview of 15 enablers, as shown in Table 9, which could potentially help scientists generate impact.

RQ4 *What can a tool look like that maps the impact of scientists?*

Based on previous outcomes a design brief was formulated and a design proposal was made and evaluated. The design proposal for the Impact Radar allowed for the creation of an overview of impact and the raising of awareness of that impact.

By asking scientists to discuss, analyse and think about the impact of their research and to let them place it in an existing map, and thus creating an overview of their impact, can give scientists awareness of their impact. Thereby answering the main question *How can a tool give scientists awareness of their impact?*.

7 Synthesis

As mentioned before, this study is part of a Double Degree between the master programme Life Science & Technology (LST) and Communication Design for Innovation (CDfI). As part of that integration of both the thesis for LST and CDfI, the Impact Radar was used to map the impact of the research performed for the thesis of LST. This is done by the author in collaboration with the supervising PhD student for the LST thesis.

Since the work performed for Life Science & Technology is confidential, full details can not be described here, therefor brief descriptions are provided per each mapped impact. Due to its confidential nature, the work performed for Life Science & Technology can not be found on the repository of TU Delft but can be requested at the Industrial Microbiology section of the Department of Biotechnology, TU Delft if necessary.

In the following sections all mapped impacts are discussed briefly, with short motivations on why these impacts were mapped and explanations for the type of impact chosen. The filled-out Impact Radar is shown in Figure 14. Impact was found in the Scientific, Technologic, Economic, Environment and Education areas, on various levels of scale. Furthermore, impact in the environmental and health area was hypothesized. This work does have any societal, cultural or political impact.

Scientific impact

Seen that the research performed for LST was part of a PhD project, the study has a direct, demonstrable and positive impact on the PhD student (individual) supervising the research. Research results led to advances in academic knowledge, can be used directly by the PhD student and will contribute to a scientific publication. *Direct was chosen because it directly influences the course of a PhD-project, demonstrable because it can be traced back to the performed research and positive as it led to new knowledge.*

As the PhD students works within a project team, all other team members can benefit for the acquired knowledge. Furthermore, a script that was written for data analysis could also be used by others. Therefore, on a local level there is also a direct demonstrable positive impact. *Direct was chosen because it directly influences the project team due to the generated knowledge, demonstrable because it can be traced back to the performed research and positive as it led to new knowledge and methods.*

As the results of this study demonstrate something thought to be impossible within the academic yeast community, this work also has a direct demonstrable positive impact on a community and international level. *Direct was chosen because it directly influences the yeast community due to its novelty, demonstrable because it can be traced back to the performed research and positive as it led to new knowledge.*

Technological impact

The research results of this study contribute to the improvement of performance of a fermentation process. This could in the future, albeit not in the near future, also lead to improvement on an industrial scale, after further research is carried out. Therefore, this study has a direct demonstrable positive impact on an organisational level. *Direct was chosen because it directly influences the fermentation process, demonstrable because it can be traced back to the performed research and positive as it leads to improvement of the fermentation process.*

Furthermore, this could also have a direct demonstrable positive impact on a local scale, as the results can be applied within the section of Industrial Microbiology immediately. *Direct was chosen because it directly influences the fermentation process, demonstrable because it can be traced back to the performed research and positive as it leads to improvement of the fermentation process.*

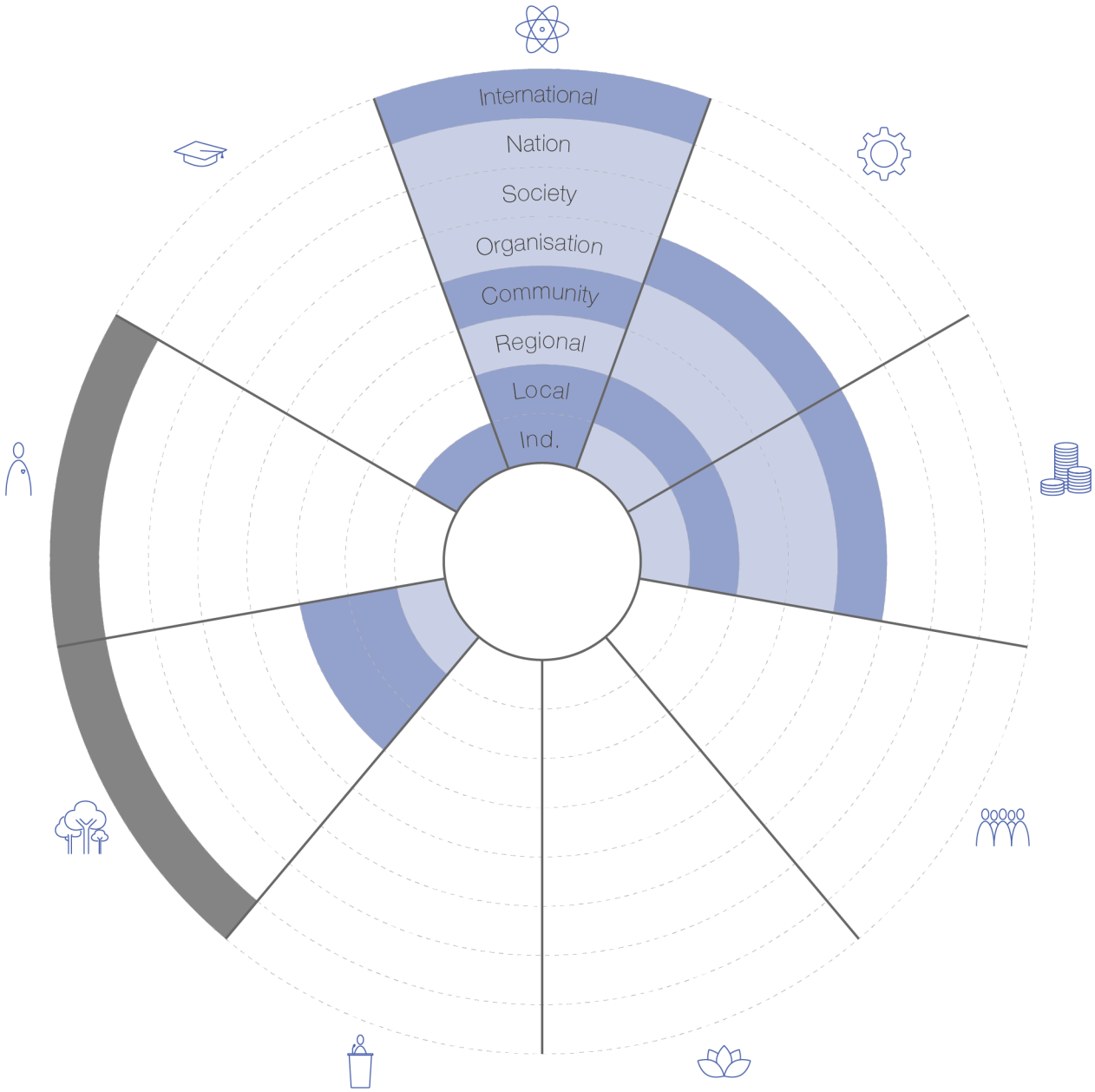

Figure 14. The mapped impact of the research performed for the master programme Life Science & Technology as part of a double degree. All blue shaded areas indicated impacts as found by the author. Light blue shaded areas indicate possible underlying impact. Dark grey shaded areas indicate hypothesized impacts.

Economic impact

By improving fermentation processes operational expenses can be reduced, thereby having a direct demonstrable positive impact on a local and organisational scale. *Direct was chosen because it directly influences the fermentation costs, demonstrable because it can be traced back to the performed research and positive as it leads to cost reduction.*

Furthermore, if the result/method is patented (which is the intention at this moment) this could also lead to economic benefits, thereby having direct demonstrable positive impact on a local scale, i.e. for the section of Industrial Microbiology. *Direct was chosen because it directly leads to income of intellectual property, demonstrable because it can be traced back to the performed research and positive as it leads to economic benefits.*

Environmental impact

Further investigation is needed to be certain of this, but this study could have direct non-demonstrable/demonstrable negative impact on the environment. As this study might have led to yeast variants that might be resistant to specific anti-fungal drugs. Therefore, it was recommended to further investigate this possible resistance. *Direct was chosen because it could directly lead to environmental risks, both non-demonstrable and demonstrable because it hard to trace it back to this study and negative as it could lead to environmental risks.*

Hypothesized:

This study might also have indirect non-demonstrable/demonstrable positive environmental impact, as it could lead to better resource management. Furthermore, it could contribute to a change from a fossil-based industry to a bio-based industry, preventing further climate change. *Indirect was chosen because it could contribute to preventing further climate change, both non-demonstrable and demonstrable because it hard to trace it back to this study specifically and positive as it could lead to preventing further climate change.*

Health impact

Hypothesized:

This study might also have indirect non-demonstrable/demonstrable positive health impact, as it could lead to preventing further climate change. *Indirect was chosen because it could contribute to preventing further climate change, both non-demonstrable and demonstrable because it hard to trace it back to this study specifically and positive as it could lead to preventing further climate change.*

Educational impact

Finally, this study contributed to finalising the degree of the author of the master programme Life Science & Technology, thereby delivering skilled people that move between academia and industry. *Direct was chosen because it was part of completing a degree, demonstrable because it shows in the curriculum of the master programme and positive as it led to the graduation of the author of this study.*

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Appendixes

Appendix I – Coding Tree Systematic Literature Review

All records included in the systematic literature review was coded using concept coding, using the concepts 'Interpretation' for all interpretations encountered in the records, 'Area' for all mentioned areas where impact is found, and 'Scale' for all mentioned levels and scales of impact. Both concepts 'Area' and 'Scale' were divided in sub-concepts. A schematic representation of this coding is given in Figure 15.

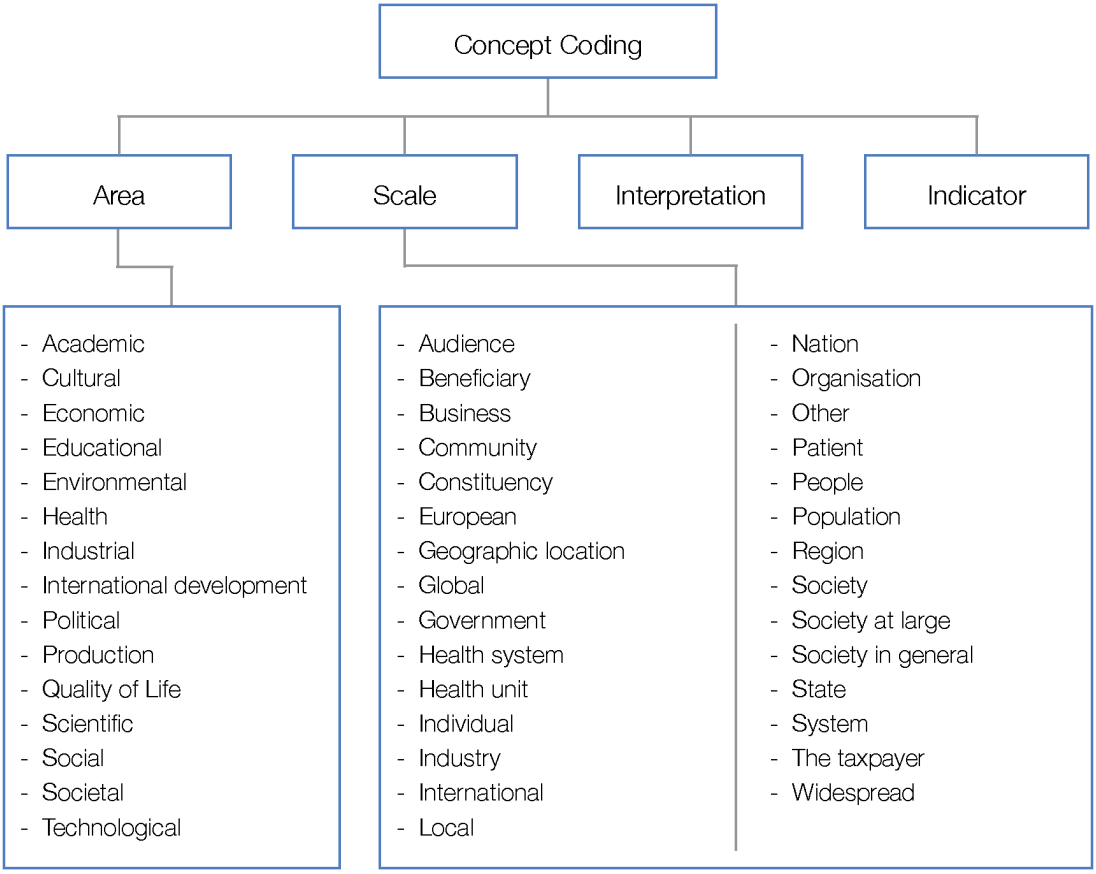

Figure 15. Schematic representation of coding tree for SLR.

Appendix II – Interpretations of 'impact'

An overview of all interpretations of 'impact' included in this study. All criteria for encoding of these interpretations are presented in Table 10 and a full list of all interpretations with codes are presented in Table 11.

Table 10. Encoding criteria for all interpretations of 'impact'. Bias, Demonstrable, Area and Scale are encoded as Present ('1') or Absent ('0'), Directness is encoded as Direct ('1'), Indirect ('0'), Interpreted-direct ('(1)') or Interpreted-indirect ('(0)').

	Present / Direct (1)	Absent / Indirect (0)
Bias	When a term with positive or negative connotations is used to describe the impact. Examples words: 'improve', 'benefit', 'positive return', 'forward', etc.	When a neutral term is used to describe impact: 'Change', 'influence', etc. When both terms with connotations and neutral terms are present.
Demonstrable	When it was specified, or implicated, that impact should be demonstrable. Example words: 'demonstrable', 'citation', 'measurable', 'direct', etc.	When it was specified, or implicated, that impact should be non-demonstrable Example words: 'non-demonstrable', 'indirect', etc. When both demonstrable and non-demonstrable words are present.
Area	When specific areas of impact are mentioned. Example words: 'economic', 'policy', 'beyond academia', etc.	When no specification for area of impact is mentioned.
Scale	When specific scales of impact are mentioned. Example words: 'individual', 'community', 'nation', etc.	When no specification for scale of impact is mentioned.
Directness	When direct impact is explicitly mentioned '1' When impact is interpreted as direct '(1)'	When indirect impact is explicitly mentioned '0' When both direct and indirect impact are explicitly mentioned. '0' When impact is interpreted as indirect '(0)'

Table 11. Interpretations of 'impact, together with the author of each interpretation, encoding of Bias, Demonstrable, Area and Scale, encoding for Directness and the origin of each interpretation. Encoding criteria are specified in Table 10.

* FPC = four-digit code; corresponding to presence or absence of Bias, Demonstrable, Area and Scale, in that order.

Interpretation of impact	Author	FPC*	Directness	Origin
"Impact is often understood as a change that research outcomes produce upon academic activities, the economy, and society at large."	(Reale et al., 2018)	0010	(0)	SLR
"Research impact, understood as the benefits from research or the payback of research, is increasingly becoming recognised as important."	(Escribano-Ferrer et al., 2017)	1000	(0)	SLR
"The first is building indicators and metrics to 'measure' impact, and assumes impact as a magnitude of forward progress."	(Reale et al., 2018)	1000	(0)	SLR
"Political impact of research occurs when knowledge is transferred, that is, when decision makers and/or social actors employ the published and disseminated results as the basis for their policies and/or actions (Flecha 2014). Although it significantly overlaps with the concept of social impact, its specific features relate to the fact that it addresses transformations that are produced in policy development and in the policy process (motivations and rationales, policy design, policy implementation, and policy assessment)."	(Reale et al., 2018)	0010	(1)	SLR
"Scientific impact is commonly defined as a change in research, which breaks the dominant paradigm and influences future research investigations."	(Reale et al., 2018)	0010	(1)	SLR
"Here, impact has been defined as including patents, licensing agreements, liaison with industry, authorised consultancy work, campus companies, placement of students or graduates, or cultural, economic and social impacts."	(Rau, Goggins, & Fahy, 2018)	0110	(1)	SLR
"In academia, research impact is commonly regarded as the extent to which a scholar's work has been used by other researchers (Bornmann et al., 2008)."	(Li, Liao, & Yen, 2013)	0100	(1)	SLR
"Despite the uncertainties related to properly defining social impact, there is general agreement in the literature that social impact is the change or the influence that research can have on society. The most debated problem is how this change takes place."	(Reale et al., 2018)	0010	(0)	SLR

Interpretation of impact	Author	FPC*	Directness	Origin
“This paper suggests that the social impact of academic research can be demonstrated by describing research activities in terms of their epistemological, artefactual and institutional-interactional dimensions: (1) the epistemological viewpoint concentrates on an increased understanding of the relevant phenomena related to societal problems; (2) the artefactual viewpoint pays attention to the instruments, methods, products or services that are transferred from university to society; and (3) the institutional-interactional dimension concerns the form of collaboration networks and field-specific institutions through which researchers interact with societal actors.”	(Miettinen et al., 2015)	0110	(0)	SLR
“Drawing on the recent definition put forth by Stephan et al. (2016), we define social impact as beneficial outcomes resulting from prosocial behavior that are enjoyed by the intended targets of that behavior and/or by the broader community of individuals, organizations, and/or environments.”	(Rawhouser, Cummings, & Newbert, 2018)	1001	(1)	SLR
“The most common definitional approach characterizes social impact in terms of externalities. Externalities are outcomes created from economic activity that exceed the objective functions of those engaged in the activity (Santos, 2012).”	(Rawhouser et al., 2018)	0010	(1)	SLR
“Impact: these are the contributions of and benefits to the scientific community (with the progression of knowledge) and to society (with practical consequences on the progression of knowledge).”	(Lima & Wood, 2014)	0010	(0)	SLR
“Considering these remarks, the social impact of research can be defined as “an influence or benefit (realized or expected) from the results of research activity to the research community or to society at large.”	(Lima & Wood, 2014)	0011	(1)	SLR
*“*A definition specific to mental health is given: Research impact is a direct or indirect contribution of research processes or outputs that have informed (or resulted in) the development of new (mental) health policy/practices, or revisions of existing (mental) health policy/practices, at various levels of governance (international, national, state, local, organisational, health unit).”	(Alla et al., 2017)	0011	0	SLR
“Social impact, defined as an effect on society, culture, quality of life, community services, or public policy beyond academia, is widely considered as a relevant requirement for scientific research, especially in the field of health care.”	(Abma et al., 2017)	0010	(1)	SLR

Interpretation of impact	Author	FPC*	Directness	Origin
“The concept of ‘impact’ in the social sciences embraces economic and societal impact in the sense of direct and often quantifiable economic benefits; wider social impacts that will benefit society more generally such as effects on the environment, public health or quality of life; and impacts on government policy, the third sector and professional practice.”	(Armstrong & Alsop, 2010)	1110	(1)	SLR
“ “The demonstrable contribution that excellent research makes to society and the economy.” The ESRC elaborates this as fostering global economic performance, and specifically the economic competitiveness of the United Kingdom; increasing the effectiveness of public services and policy; and enhancing quality of life, health and creative output.”	(Pardoe, 2014)	1110	(1)	SLR
“The Research Councils of the UK (RCUK), responsible for the expenditure of about three billion pounds a year public resource on academic research, have also moved to prioritise impact though RCUK adopts a broader definition of impact as ‘the demonstrable contribution that excellent research makes to society and the economy’, embracing ‘all the diverse ways that research-related skills benefit individuals, organisations and nations.”	(Bannister & Hardill, 2013)	1111	(1)	Alla et al. (2017)
“Research Councils UK, for example, has defined impact as ‘recognising the diverse ways in which research can contribute to the UK economy, including social, environmental, cultural, health and policy benefits as well as more obvious economic benefits’.”	(Halse & Mowbray, 2011)	1010	(1)	Alla et al. (2017)
“Academic impact: The demonstrable contribution that excellent research makes to academic advances, across and within disciplines, including significant advances in understanding, methods, theory and application.”	(Jones & Cleere, 2014)	0110	(1)	Alla et al. (2017)
“Economic and societal impacts: The demonstrable contribution that excellent research makes to society and the economy. Economic and societal impacts embrace all the extremely diverse ways in which research-related knowledge and skills benefit individuals, organisations and nations by: fostering global economic performance, and specifically the economic competitiveness of the United Kingdom, increasing the effectiveness of public services and policy, enhancing quality of life, health and creative output.”	(Jones & Cleere, 2014)	0111	(1)	Alla et al. (2017)
“The UK’s Research Excellence Framework (REF) defines impact as ‘reach’ and ‘significance’ and can encompass the ‘effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia’.”	(Association of Commonwealth Universities (ACU), 2016)	0010	(0)	Alla et al. (2017)

Interpretation of impact	Author	FPC*	Directness	Origin
“The definition pursued in the REF is different in crucial respects. HEFCE’s website says the following about impact. ‘For the purposes of the REF, impact is defined as an effect on, change or benefit to the economy, society, culture public policy or services, health, the environment or quality of life, beyond academia. Impact includes, but is not limited to, an effect on, change or benefit to: the activity, attitude, awareness behaviour, capacity, opportunity, performance, policy, practice, process or understanding of an audience, beneficiary, community, constituency, organisation or individuals in any geographic location...’”	(Brewer, 2013)	0011	(1)	Alla et al. (2017)
“Impact was defined as occurring when academic research led to ‘... benefits to one or more areas of the economy, society, culture, public policy and services, health, production, environment, international development or quality of life, whether locally, regionally, nationally or internationally’ and as ‘...manifested in a wide variety of ways including, but not limited to: the many types of beneficiary (individuals, organisations, communities, regions and other entities); impacts on products, processes, behaviours, policies, practices; and avoidance of harm or the waste of resources’.”	(Greenhalgh & Fahy, 2015)	1011	(0)	Alla et al. (2017)
“Similarly HEFCE and Star Metrics have operationalised research impact as the benefits and returns that research brings to the economy, environment, international and social arenas, public policy and services, and to the quality of life, culture and health of individuals and communities.”	(Halse & Mowbray, 2011)	1011	(1)	Alla et al. (2017)
“The REF defines impact as ‘any identifiable benefit to or positive influence on the economy, society, public policy or services, culture, the environment and/or quality of life’. Impact includes, but is not limited to, an effect on, change or benefit to: the activity, attitude, awareness, behaviour, capacity, opportunity, performance, policy, practice, process or understanding; of an audience, beneficiary, community, constituency, organisation or individuals; and in any geographic location whether locally, regionally, nationally or internationally.”	(Hartwell et al., 2013)	1111	(1)	Alla et al. (2017)
“When the benefits from research are tangible, measurable and recognised outside of academia, research is said to have impact. This could be economic, environmental or cultural. Research impact can include changes to public policy, health care or quality of life. Research impact is defined as involving changes in practice, knowledge and understanding, attitudes and ideas resulting from research.”	(Schnitzler et al., 2016)	0110	(1)	Alla et al. (2017)
“The REF similarly encompasses ‘any social, economic or cultural impact or benefit beyond academia’ and also includes public engagement activities.”	(Wilkinson et al., 2012)	1010	(0)	Alla et al. (2017)

Interpretation of impact	Author	FPC*	Directness	Origin
“In the context of this overview, the term ‘research impact’ refers to any type of output of research activities which can be considered a ‘positive return’ for the scientific community, health systems, patients, and the society in general.”	(Banzi et al., 2011)	1011	(1)	Alla et al. (2017)
“The Arts and Humanities Research Council (AHRC) has shown considerable interest in establishing impact within their remit and say, ‘By impact we mean the “influence” of research or its “effect on” an individual, a community, the development of policy, or the creation of a new product or service. It relates to the effects of research on our economic, social and cultural lives.’”	(Chandler, 2013)	0011	(0)	Alla et al. (2017)
“Impact in its simplest definition is about making a difference, so there is action or activity which leads to change, but that change needs to be seen within a context which may be global, local or even individual. Also, the nature of change needs to be considered, whether it is related to people, systems, environment, knowledge, understanding or policy. /-/ The nature of impact is identified as the influence, effect, demonstrable contribution, change or benefits that result from the research.”	(Chandler, 2013)	0111	(1)	Alla et al. (2017)
“Research impact denotes the benefits or returns from research, which flow beyond the academic realm to ‘end users’ or research. These end-users are traditionally defined as industry, business, government, or more broadly, the taxpayer.”	(Donovan, 2008)	1011	(1)	Alla et al. (2017)
“For purposes of program and portfolio evaluation, we define impacts to be the benefits or changes resulting from scientific research, program activities or outputs.”	(Drew, Pettibone, Finch, Giles, & Jordan, 2016)	0000	(0)	Alla et al. (2017)
“The term research impact describes the effects and outcomes, in terms of value and benefit, associated with the use of knowledge produced through research.”	(Primary Health Care Research and Information Service (PHCRIS), Beacham, Kalucy, & McIntyre, 2005)	1000	(1)	Alla et al. (2017)
“Perhaps the least unsatisfactory definition is that of the NERF subgroup report on impact (2000), which characterises impact as ‘the influence or effect that educational research has on its audiences’.”	(Kanefsky, 2001)	0001	(0)	Alla et al. (2017)
“In the context of this review, research impact is defined as: ... any type of output of research activities which can be considered a ‘positive return’ for the scientific community, health systems, patients, and the society in general.”	(Milat, Bauman, & Redman, 2015)	1011	(1)	Alla et al. (2017)

Interpretation of impact	Author	FPC*	Directness	Origin
“By ‘impact’, we are talking about beneficial changes that will happen in the real world (beyond the world of researchers) as a result of your research. This can include ‘negative impacts’ such as evidence that prevents the launch of a harmful product or law. Impacts may occur in the immediate or long-term future, and there can be challenges tracking and attributing impacts, which this book will help you explore.”	(Reed, 2016)	1000	(1)	Alla et al. (2017)
“The Flinders University Primary Health Care Research and Information Service provided a definition of research impact that was adapted for this project: ‘’The term research impact describes the effects and outcomes, in terms of value and benefit, associated with the use of knowledge produced through research.”	(Sarli, Dubinsky, & Holmes, 2010)	1000	(1)	Alla et al. (2017)
“Impact in this article refers to how the research findings were used to promote change either at the individual level or in the systems, environment or policy realms.”	(Sanon, Evans-Agnew, & Boutain, 2014)	0011	(1)	Alla et al. (2017)
“Research impact is, in general, the effect research has beyond academia. The York Research Impact Statement describes research impact as ‘...when the knowledge generated by our research contributes to, benefits and influences society, culture, our environment and the economy.../-/...translating research into real-world outcomes, benefitting health, prosperity and well-being of people and society.’”	(University of York, 2015)	0011	(0)	Alla et al. (2017)
“Broadly defined, research impact is the ‘demonstrable contribution that research makes to the economy, society, culture, national security, public policy or services, health, the environment, or quality of life, beyond contributions to academia’.”	(Australian Research Council (ARC), n.d.)	0110	(1)	Alla et al. (2017)
“Research impact is defined as the social, economic, environmental and/or cultural benefit of research to end users in the wider community regionally, nationally, and/or internationally.”	(Department of Education Science and Training, 2006)	1011	(0)	Alla et al. (2017)
“For example, the EAG had defined research impact as the ‘social, cultural, economic, and/or environmental outcomes for industry, government and/or other identified communities regionally within Australia, nationally and/or internationally’.”	(Donovan, 2008)	0011	(0)	Alla et al. (2017)
“The definition of impact is extended: ‘Impact refers to the extent to which research has led successfully to social, economic, environmental, and/or cultural benefits for the wider community, or an element of the community’, which allows inclusion of private value in addition to public value.”	(Donovan, 2008)	1011	(1)	Alla et al. (2017)

Interpretation of impact	Author	FPC*	Directness	Origin
"'Research impact' is defined within the RQF as the beneficial application of research to achieve social, economic, environmental and/or cultural outcomes. This is not to be confused with impact in the academic domain which is seen more as an indicator of the intrinsic quality of the research on scholarly or academic measures."	(Duryea, Hochman, & Parfitt, 2007)	1010	(1)	Alla et al. (2017)
"Research Impact is the social, economic, environmental and/or cultural benefit of research to end-users outside the peer academic community. /-/ And according to the Australian Government, your research has made an impact if it produces 'identifiable social, economic, environmental and/or cultural benefit for the wider community'."	(Onslow, 2008)	1111	(1)	Alla et al. (2017)
"The LSE's maximising impact handbook, though, defines 'a research impact' as 'an occasion of influence' rather than what might happen as a result of that influence."	(Association of Commonwealth Universities (ACU), 2016)	0000	(0)	Alla et al. (2017)
"The ESRC's website goes on to say: 'research impact embraces all the diverse ways that research-related skills benefit individuals, organisations and nations. These include: fostering global economic competitiveness of the United Kingdom increasing the effectiveness of public services and policy; enhancing quality of life, health and creative output. A key aspect of this definition of research impact is that impact must be demonstrable. It is not enough just to focus on activities and outputs that promote research impact, such as staging a conference or publishing a report. You must be able to provide evidence of research impact, for example, that it has been taken up and used by policy makers, and practitioners, has led to improvements in services and business'."	(Brewer, 2013)	1111	(0)	Alla et al. (2017)
"Policy or practice impacts were defined as demonstrable changes, or benefits to products, processes, policies, and or practices, that occur after a research project has concluded. These impacts are concrete, measurable changes in policy or practice such as a new government policy, a change in organizational or clinical practice, a health education campaign or related new funding that can be attributed to the research intervention in question. Impacts at this level could also include stopping or changing existing interventions following demonstration of intervention ineffectiveness. Policy or practice impacts can be widespread or localized, and may benefit specific or general populations."	(Cohen et al., 2014)	0011	(1)	Alla et al. (2017)
"In Finland the quality of research, research activity, impact of research, activity in educating young scientists and activity in the scientific community are identified as appropriate criteria for assessing quality of research; within this assessment, research impact is defined in terms of citations by other researchers (in journal articles, books, published conference proceedings, and PhD dissertations), invited and plenary presentations in international conferences, and the number of foreign co-authors in journal articles."	(Harland, 2013)	0100	(1)	Alla et al. (2017)

Interpretation of impact	Author	FPC*	Directness	Origin
“We define a research impact as a recorded or otherwise auditable occasion of influence from academic research on another actor or organization. Impact is usually demonstrated by pointing to a record of the active consultation, consideration, citation, discussion, referencing or use of a piece of research.”	(LSE Public Policy Group (PPG), 2011)	0100	(1)	Alla et al. (2017)
“In this paper we are concerned with two important aspects of research performance: output and impact. Output refers to the extent to which the research creates a body of scientific results. Impact is defined as the actual influence of the research output on surrounding research activities.”	(Moed, Burger, Frankfort, & Van Raan, 1985)	0000	(1)	Alla et al. (2017)
“On a macro-level of research impact, three factors will determine the overall impact of research: the geographical and disciplinary extent to which research output has been diffused, the adoption where the overall impact I is defined as the product of the extent (E) of knowledge diffusion, in which citation data can be utilized to analyze the rate and scope of knowledge diffusion, the rate of adoption (A) as represented by the proportion of intellectual property that has been licensed or purchased among all produced, and the benefits (B) to society in both quantitative and qualitative terms.”	(Qin, 2010)	1110	(1)	Alla et al. (2017)
“The term ‘research impact’ in this study is defined as the number of times that each article is cited in the literature.”	(Tonta, Ünal, & Al, 2007)	0100	(1)	Alla et al. (2017)
“Before analysing the social and cultural impacts of research, it is first necessary to define what we mean by ‘impact’. The impact(s) of research occur when others besides the research group itself notice the results, refer to these results, use the results or even commission further research. Outcomes of research can eventually lead to societal changes, generally called societal impact. Societal impact can be further differentiated into social (public sector), economic (private sector) and cultural impacts; however these impacts often overlap.”	(Cox, Cozzens, Ark, McCauley, & Borbey, 2010)	0010	(1)	Alla et al. (2017)
“Research impact is defined as the application, use and influence of research across various categories.”	(Hargreaves, 2012)	0000	(1)	Alla et al. (2017)
“Although other definitions exist for the main types of research use and impacts, in this study we use the following definitions: ‘Instrumental use or impact’ refers to the direct impact of research on policy and practice decisions where a specific piece of research is used in making a specific decision or in defining the solution to a specific problem.”	(Meagher, Lyall, & Nutley, 2008)	0110	1	Alla et al. (2017)
“Conceptual use or impact’ is a more wide-ranging definition of research use, comprising the complex and often indirect ways in which research can have an impact on the knowledge, understanding and attitudes of policy-makers and practitioners.”	(Meagher et al., 2008)	0010	0	Alla et al. (2017)

Interpretation of impact	Author	FPC*	Directness	Origin
"In order to define research impact, the spectrum of impact from conceptual to instrumental set out by Nutley et al (2007) was used as a starting point. Changes in awareness, knowledge and understanding, ideas attitudes and perceptions, and policy and practice as a result of research."	(Morton, 2015)	0000	(0)	Alla et al. (2017)
"Within this review, research impact was defined along a continuum, ranging from raising awareness of findings, through increasing knowledge and understanding, to actual changes in decision-making or decisions. These can be thought of as conceptual uses at one end of the continuum and instrumental uses at the other."	(Walter et al., 2003)	0000	(1)	Alla et al. (2017)
"The Economic and Social Research Council adopts a broad understanding of impact, encompassing: economic benefits; effects on the environment, public health and quality of life; impacts on policy and practice in governmental, private and third sector organisations; knowledge exchange impacts, such as relationships that might facilitate future knowledge exchange."	(Wilkinson et al., 2012)	0011	(1)	Alla et al. (2017)
"Impacts: In the context of evaluating health research, the overall results of all the effects of a body of research have on society. Impact includes outputs and outcomes, and may also include additional contributions to the health sector or to society. Impact includes effects that may not have been part of the research objectives, such as contributions to a knowledge based society or to economic growth."	(Canadian Institute of Health Research (CIHR), 2005)	0010	(0)	Alla et al. (2017)
"Impacts, often called outcomes, are the effects of the research on the research field or within society."	(Drew et al., 2016)	0010	(0)	Alla et al. (2017)
"To address this need to demonstrate the impact of research on people's health, we can use a model that shows different levels of the impact of research. This model was developed by AHRQ staff and consultants who conceived of a pyramid of outcomes that included four different levels of impact (Figure 1), beginning (at the pyramid's bottom) with impact on knowledge and further research (level one) and ascending (at the pyramid's peak) to impact on health outcomes (level four). In between are impact on policies (level two) and impact on clinical practice (level three)."	(Eisenberg, 2001)	0110	(1)	Alla et al. (2017)

Appendix III – Semi-structured interview protocol

Interview script English.

What is impact for you? / When do you have impact?

Which of the following words would best fit with impact?

Influence, improve, affect, effect on, change, benefit

Do you think this interpretation matches with others (here at TU Delft)?

What impact would your research have, and where would you see that impact?

Would there be other areas where you could have impact?

Could you imagine having impact in one of the following 'areas', why would or wouldn't you?

Scientific, Technologic, Economic, Societal, Political, Cultural, Environmental, Health or Education

Where do you think you've had the biggest impact with your research?

How big would that impact be? / Who did it affect?

Individual, local, region, community, organisation, society, nation or international

How did you achieve that impact? / What was necessary to achieve this?

How long did it take to achieve that impact?

Do you think it always takes that amount of time?

Short, medium, long

Do you think that 'X' is the only thing you need to make impact? If yes, why; if no, what else, and why?

Has it occurred that, after trying for a long(er) period of time, something did not succeed? If yes, what do you think was missing here to make an impact?

Interview script Dutch.

Wat is impact voor jou? / Wanneer heb je impact?

Welk van de volgende woorden zou het best bij impact passen?

Influence, improve, affect, effect on, change, benefit

Denk je dat dit overeenkomt met anderen (aan de TU Delft)?

Wat voor impact heeft jouw onderzoek en waar zie je die impact? *sector

Zijn er andere gebieden waar je impact kunt hebben?

Zou je impact kunnen voorstellen in een van de volgende 'sectoren', waarom wel of niet?

Scientific, Technologic, Economic, Societal, Political, Cultural, Environmental, Health or Education

Waar heb je zelf de grootste impact gehad met je onderzoek?

Hoe groot is die impact dan? Waar heeft het effect?

Individual, local, region, community, organisation, society, nation or international

Hoe heb je die impact bereikt? / Wat had je nodig om dit te bereiken?

Hoe lang heeft het geduurd voor je die impact had?

Denk je dat dat altijd op deze tijdsspan is?

Short, medium, long

Denk je dat 'X' het enige is wat je nodig hebt om impact te maken? Zo ja, waarom; zo nee, wat nog meer, waarom?

Is het weleens voorgekomen dat iets, na lang proberen, niet geslaagd is? Zo ja, wat denk je dat hier dan miste om impact te maken?

Appendix IV – Coding Tree Interview Transcripts

All interview transcripts were coded using concept coding, for the concepts ‘Area’, ‘Scale’, ‘Enabler’ and ‘Barrier’. Both concepts ‘Area’ and ‘Scale’ were divided in sub-concepts, based on areas and scales selected in the first part of this study. A schematic representation of this coding is given in Figure 16.

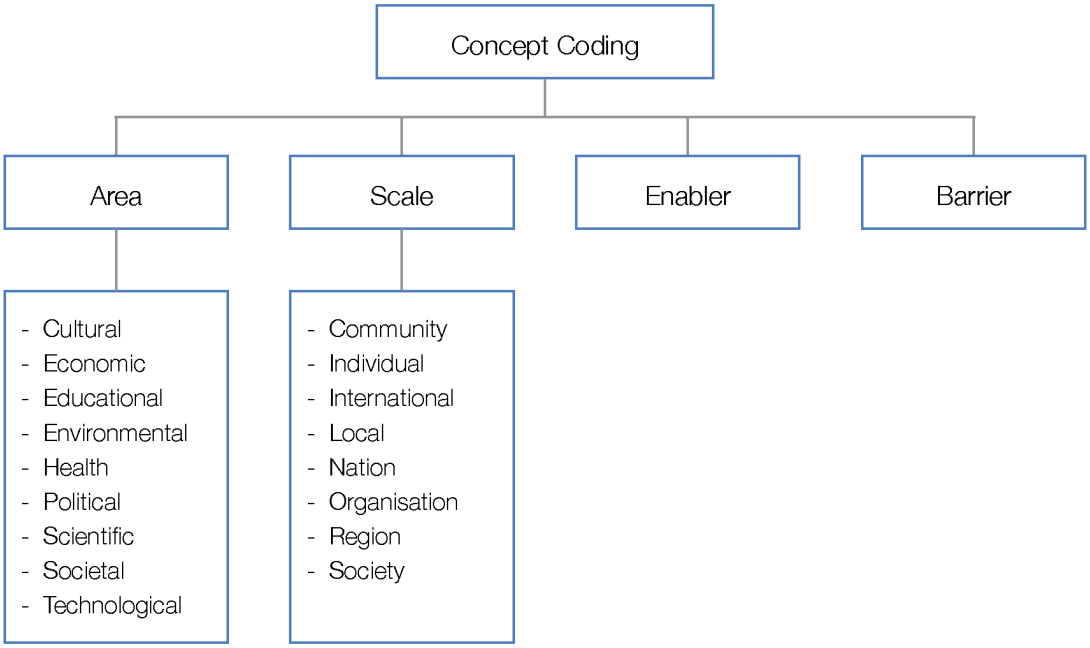

Figure 16. Schematic representation of coding tree for transcripts.

Appendix V – Example Transcript Semi-Structured Interview

Below the transcript of a semi-structured interview with participant 6 is given. All text formatted like [**Example**] denotes the interviewer, all text formatted like [Example] denotes the interviewee. The audio files and full transcripts of all performed interviews (10 interviews) can be requested via the Department of Science Education & Communication.

So, for my SC masters I also have to do a thesis, and my thesis is about impact, and more precisely about the impact after scientific research. And it is because impact is becoming more and more important, within the scientific community, or at least there is a more, more focus on making impact. And the TU Delft has developed a strategic framework which is focused on Impact for a better Society. So, it's being discussed more and more, but actually there is a lot not known about impact, so I was very curious to find out more about it. So, my first question would be, to you, what do you think for you impact means?

Well, the word impact means that whatever you do influences something else, as the word impact says, has an impact on something else. And the first and foremost target of the TU Delft, and of any university, whether it is a university of technology, or a university, is the education of a new generation, of young people. And the first and foremost impact of the university is that we educate these young people, to be people that think along scientific lines, that are well educated and think critically. And the prime example where you can see that a well-educated next generation is necessary, and in this case, it is not the universities delivering it, is climate change, and the movement of the student, actually pupils, so the generation that hasn't even seen university. And now what does our science and our research with impact. So, in order to achieve this target, of well-educated young people, that know how to critically thing, you have to perform cutting edge research, and this idea is not at all new. This idea was already voiced more than 200 years ago and was the fundamental thought behind founding many universities in Europe in the 19th century, beginning of the 20th century, second half of the 20th century. So that's all not new, and the last thing, how much influence this has on society, this is of course also not new. This was also from the very beginning one of the targets, we educate our people in order to have well a highly trained population and much higher value added in this industry, rather than just purely based on muscle and labor industry. And you can see that in every country, that went for higher education that took place, and China is I think is one of the last examples, but before China many of the Asian countries did this, and throughout the same applies because after the second world war there was an entire gulf of forming universities in order to educate the people, and that led to a shift of blue collar work to white collar work in Europe. And what some people now think is now tragic and that is the de-industrialization of Europe and that you can from a scientific from an environmental point of view argue against it.

Is this also your personal vision, because you started explaining your answer with what impact should be for the university, or the goal of a technical university, is your own vision of impact in line with that?

Yes. So, one of the reasons why I'm at the university, work at the university, because I truly enjoy performing research and doing this together with young people and training them and doing research. And the research is always curiosity driven, and it is nice, and I think my personal vision it should have a link to societally relevant subjects. But then it is rather difficult what is societally relevant, because if you look at the topic that is nuclear power, some people think that is the solution to everything, and other people think that's the demon you shouldn't touch. So, it is a little bit tricky if you look at this. Similarly, if you look at a topic like carbon capture, where they say we take CO_2 and pump it in this used gas field, yeah, that is a proposition that is being made by countries that have gas fields, but there are also several, or there have been incidents in the past, where naturally occurring CO_2 was released, and that lead to

many deaths. So, there were 1 or 2 incidents in valleys in Africa where this happened, where a lake was first saturated with CO_2 and when it became oversaturated the co2 was released into the environment and lead to many deaths. So, if you would have had this somewhere in Europe, no one would be talking about carbon capture. but this just shows how it is difficult to define what is societally relevant. and then you can very quickly say that something like astronomy is perhaps entirely relevant, but on the other side, but if you hadn't had a glance in to the skies, we might have never had discovered the ozone hole. Which was… It is very difficult to define societally relevant. And that is why I'm saying that we first and foremost impact of the university is the education of critical minds that are capable of evaluating and having a good look and seeing whether what has been handed down to them was correct or whether some aspects of this are wrong. And there is, so my background is I'm German, as you know, or as you might know, and one of my examples that is always thought in Germany. Is that Max Planck, when he came up with the fact that you have energy in quant, in these little units, and this, so when the older generation of physicist, no that theory is wrong, his answer was well then we need to teach a new generation what is correct. And this always holds true at the university y and renewing science, by teaching a new generation is the main target of valorization.

Do you think that this vision is shared with all the people that work at the university?

I think all of the, or the vast majority of the people at the university share this vision. But they add a lot more practical applications to it. And if you look at the current political climate, then it is very clear that this is what is asked for, and this is why we normally add this, and I normally add this when I talk to bodies that give us the money.

Now coming to a bit more into the research that you do, could you briefly explain what research is performed in your research line, or research group?

Yes, so we very fundamentally have a look at the chemical reactions, or basically we have a fundamental look at organic chemistry, we see which reactions do not work well and we have a look at how to improve them and our tool that we use for improvement is biocatalysts, because biocatalysis is environmentally benign, in most cases it is environmentally benign, but you always have to check this after you start with the improvement, or before starting improving you should check whether you can really reach the target of environmentally benign. So, what we want to achieve is that we replace reactions that work with a low selectivity of do not work at all, with highly selective and high yielding reactions. So that instead of converting A into B, what you want to have, plus also D E and F, because they are side products, due to lack of selectivity, you really only convert A into B and nothing else. And biocatalysts is a tool for this, and of course we then also want to understand how the biocatalysts works, and then the other aspect of it is how do I perform a reaction, so not only which catalyst do I use, so a biocatalyst, but is it better to do this in batch, or is it better to do it in flow. But it is all geared towards converting our currently unsustainable chemistry towards a sustainable and environmentally benign chemistry. So, the overall idea, the overall societal target, is to set a sustainable society.

And where would you say that this research that you've been doing would have an impact.

Now there is a direct industrial impact, because we perform this research in part together with industry, and the methodologies we develop are all published, or industry first has the right and then published, and they can be implemented. And so, the search is always for developing better chemistry, and significant part of our research is done in collaboration with industry, but whether we do this in collaboration with industry or not, all of our data is available and can be implemented.

Do you think that maybe indirectly there are other sectors that might benefit from the research that has been done?

I am pretty sure, but that is something you can't predict. You simply can't predict this. this is a very general problem, if you say, I want to predict that the 1 billion that i put into the university will lead to so much product. If you want to do this, then go to a company not to a technical university. Because, as I said, one of the, and this is also defined by law, in the Dutch law, so the target of the university is education nada research, and only if you would scrap as target education, you could start doing i put so many millions in to and therefore I want so many millions out of it. And then again, if you do this money wise, you can always ask whether that money wise output is actually good for the society. Because then you end up in the systems which part can you catch in money and which part do you actually not see in money. Because, in many cases if you do a very intensive farming for instance, you might have a very profitable farming sector, but you might destroy your own environment, and since that is not costed, you don't see it. So, if you ask these arguments, this is very tricky, just like it is not directly to be shown by us, that if I teach one person, our society will have an added value of that, directly by that one person. But very much in general, if I educate my society, then i see that my society has a higher value-added industry, typically, and the living standards typically rise. So, there you can make this one to one correlation, but if you want to put this down on money, then it becomes very tricky. And then you are actually industrially busy, and you are not at the university.

But I do see possibilities, that the research that has been done, replacing conventional chemistry pathways with a new one that has environmental impact as well.

Yes. So, what you asked me, earlier, in impact, yes directly, we also collaborate with industry, so these things can be implemented by industry if they want to, but this is not my target, and not, or it is nice if it happens but it is not my personal target to achieve this. This is not the job of a university this is outside of a university, and we also don't have a profit in mind at the university in terms of money. A university is an institution where you spend money, it is not an institution where you make money, that was different in the past. There were universities, when universities were founded hundreds of years ago, the tuition fees were so high that you could make a profit with the university, that does not exist anymore. At least I'm not aware of an example where it does exist. But I do know the university where I studied was originally founded 17whatever, with the earmark of making money. So that must have existed a few hundred years ago.

Ok, so we are better off right now, probably.

Yeah, well, whatever is better, that is also tricky to evaluate.

If you look at your research that has been performed up to now, where would you say you've had the biggest impact, if you had to name something, besides maybe education.

I would always education foremost, none of the stuff that we have developed has been industrialized directly, we have performed research in parallel or that adds to industrial processes that are running in the Netherlands, and that might have turned a screw due to this, but I, so a direct industrial example from our work here, that I have performed, I do not have. So, the main impact is really education and I don't know to which extent this stuff is otherwise implemented by industry, because I was not involved. And I also have to admit that it's nice, but it is not my main target.

In the case of education then, what would be the best possible factors that influence giving the right education? Are there conditions for them to receive the best education?

Here the university, or what do you mean?

For you, how would you say your way of educating the younger generation would be key in accomplishing the best education for them, from your perspective.

I think actually the education they receive is pretty close to that, I think they have to learn the foundations of your subject that you want to master in addition to the surrounding fields, so that you're not, that you don't stand in splendid isolation. And at the same time, you have to learn, and see and realize, the gaps in the knowledge that exists, so what you can see in school is typically that what you learn is always what we know. And it is very much handed down in a way, look what we know, and it is not encouraging people to see where are the gaps in our knowledge, so I mean if you learn a language there is also no gap, because the language is simply the language, but if you look at physics, or you look at chemistry, or you look at the engineering sciences or at biology, than you will learn what we know, and the emphasis will not be on 'and we don't know all of this'. And the switching point has to be somewhere during the bachelor, where you have to switch from, this is all we know, to adding, and if we know this, then obviously all of that we don't know. And that is what research is about. Find out what that is. Find out where there are discrepancies between the thing we know. And that is what I mean by training a critical mind, and if you realize this, there are gaps, then you can see also where you can get the highest and the most interesting research, but potentially, in terms of knowledge, also that which is more valuable to society and to yourself. And the research we perform is all linked to this, because as I just explained, what are the gaps, and if you take, so I'm a chemist, if you take the chemistry textbook ,and you have a look of it form the point of view, what can you actually not do, rather from a point of view, what can you do, you will find that that is actually, there is a lot more you cannot do than what you can do. and a lot of what we can do, we can't do it very well.

While doing this research, and educating, these people, of course research papers get published eventually, is that then of a lower priority for you?

No, that is an integral part of it, because that is showing that you have achieved a target, or you found out that doesn't work, so if you do all of this research, it is essential that it is shared with the public, and I also think that it is a particularly rewarding part of a particular master thesis that you publish what you've done. So that you can see that all the training you received has actually led to you being part of the scientific community and you being able to communicate with other scientists and contributing to it. And as far as possible I always aim for the MEP to be something that you can publish in a paper. And ideally with the MEP student as the first author, but that doesn't always work. But if the research, I mean it is a limited period of time, but if the research works fine, and the student is good, then they typically manage to achieve a paper themselves where they are first author, and the PhD student, or Post Doc that supervised them in the lab is the second author. And if the topic was more difficult, or the student achieved a little less for other reasons, than the sequence of authors turns around. And the same holds of course for bachelor students, but bachelor students typically are not first authors, because the period of time is so small, and also the knowledge that they have is not that high yet, so they typically cannot achieve that. But that has also happened in the past, so there is one or two papers where a bachelor student is the first author.

That is really cool. If you look at those papers being published, do you then always aim for the journal with the highest impact factor, or more, is that of great importance when you publish.

Well the most important about publishing is that the people to whom this is potentially of interest read it, and see it, so it should be published in a journal that is generally read by everyone and that potentially has the interest in this and then, so that is the first and foremost point, and then of course if you look at the range of journals, then you aim for the one with the highest impact yes. But that is not the foremost target.

Of course, there is something as the h-index, that is sort of coming from publishing, and then eventual the citations. Do you attach a lot of value to the h-index?

I personally that the h-index is pretty nonsense, and I think that part of the funding bodies are also moving away from it, because the h-index says something about how often papers have been quoted, and if you work in a field where there are many people your papers will be quoted more often. So, someone who starts a new field, will be quoted less often, while the work might be much more important, because it is starting a new field. And so, if you look at this, then what you typically see, then scientist that are very good, and very productive, typically have a higher h-index, so there is a often a correlation but it is nothing else than a slight indication. Just like you have a habit of thinking that someone who has been educated at the TU delft will be a good future employee, because normally deliver good students but also the TU Delft has delivered student that didn't perform that well later on.

There is always of course always a standard deviation.

I don't think that these are really relevant.

Do you think reflecting on how the TU Delft looks at their academic staff, because publishing is of course what the TU Delft wants you to do, do you think that is too strict, or that is maybe…

I think publishing is what everyone should want to do who works at the university, because we do research here, funded at least in part by the general public, with the projects together with industry this is a different story, and next to training a new generation of scientist, we generate scientific knowledge and we should make this available, and if we don't publish it, but keep it in a drawer, that would be exactly the opposite of what we should do.

But there is not enough, no too much pressure to publish?

I have personally not experienced that there is to pressure, I do know that people talk about this, and in the past the TU had a funding scheme where you got more money as a faculty if you published more. Which of course logically, could lead to people writing more short papers than one long paper. But this is, which has also been scrapped again. This has been disposed of, because realized that this was not a good idea. But very much in general, if you have performed research, even if the result is not very nice, I think you should publish it, for the simple reason that you then prevent someone else of trying this as well. If you find out something doesn't work well, and you don't tell the public, so you don't put it in the scientific literature, and someone else has the same idea as you had, and you back then also thought it was a brilliant idea, it turned out not to work, then you don't want the other person to do the same thing again. So i do think that you should not only publish your most brilliant result, but i think you should publish what you've done.

Sort of a take one for the team, if I put it in plain language.

Yes, it is, you generate knowledge, and you should make the knowledge available. And that you of course with a result which is not very positive cannot end up in a high-ranking journal, well that is part of how our publishing system is organized. And that is also something where you can see the vanity of scientists, you know, like you always want to have the high-ranking stuff, it is also a bit the vanity fair.

Yes, I've heard that before, in other interviews as well, that science has ego driven sometimes.

Oh, not only sometimes, I don't think many people want a Nobel prize if they had a certain ego drive. And I also don't think that it is necessarily bad, you should do the research to find out, and you should

be proud of if and publish it. But it does make it more difficult to then publish a negative result. Which I do think you should do. Because you prevent others from performing the same research again, because what's the point that you tell someone, I tried this and didn't work, and that person says, yeah, we also tried that 10 years ago, didn't work he, yeah, good. So, then we just a lot of time and effort, on fining out the same thing again, and then we both don't publish it, and then in 5 years' time someone said: 'oh we've tried that, and it didn't work', that is ridiculous. And for someone like me, who doesn't stand in the lab anymore, I can then say, ok this is not so bad, but for the person in the laboratory this is of course highly frustrating, you do something and it doesn't work, and then you hear afterwards that two others somewhere also tried it and it didn't work. And that is not exactly very nice, and sometimes it means that you hide your negative result, or how you want to call it, in a paper you say one sentence, like, that was attempted but did not work. But you do put it into the public.

If you look at the PhD, and post docs that you supervise, do they often continue in academia or do they move away to industry?

Most of them move away, but that is also the way it should be. So, half the students that study LST continue with a PhD, and as a significant demand in industry, and also in other institutions, for people educated at a PhD-level, and I have to add to this, that when I studied myself, chemistry, more than 90% of the students did a PhD, because you did not get employment with just a degree. So, I think a PhD is part of the educational process, in the engineering sciences this is less the case. And I know that from the master CE here, the vast majority goes into industry directly. But so LST is a relatively science-based master and, at least, 2 of the specialization are relatively science based, and typically 50% of our students do a PhD, this is also because their later employers expect them to have a PhD. So, it is not unusual.

Looking at it from the point that the university educates people, and you find it very important that people are educated well, I could also foresee that the PhDs and post docs that work in your group also aspire to educate the newer generations.

To become educators, yeah, I think it is nice, but it is not, it is their choice. I don't want to, I mean if they ask me I will help them, in whichever direction they want to go, but I don't think I'm the person to tell them, right. I mean they ask me for advice, I give them advice, and I help them.

I think I most of the information for the interview right now. I thought it was very interesting you were very focused on the education part and that is something I did not hear as much in the other interviews that I've done so far. So, I think that is a very interesting conclusion, that it is so many different facets at one place.

Glad to hear that. I can one point of view perhaps, which I again bring because of my German background, so when I see, in terms of valorization, the idea that we should collaborate more with industry, and that industry should help direct, or whatever our research. I would like to point out that this is system that the former communist Eastern Block in Europe chose. So, in the entire of the communist, so east Germany, Poland, Chez Republic, Hungary, Romania, Bulgaria, Soviet Union, was very much industry telling academia what they should do. And I don't think that was a very successful model. So occasionally I'm quite surprised that the so-called free market liberals, very much tend towards this what I know as a communist model. And I actually think the free market people should not aspire towards communism, at least to me this is a little bit contradictory, so when I listen to this that the university should serve more national industry, then I very much think of what has happened in eastern Europe in the past and that didn't do the industry nor the universities there very much good. And of course, there were lots of other parameters why it didn't develop well, but that was one of the parameters and I do think we should be careful of going down that road too far.

That is a very interesting notion. Thank you very much for your time, and all the answers to my questions.

My pleasure

And I will let you know if something interesting comes out of my research.

Yeah, I would like to see the final result

Thank you very much.

Appendix VI – Potential Enablers and Barriers for Impact

An overview of all enablers and barriers identified from interviews with staff members of the Department of Biotechnology at TU Delft.

Table 12. Enablers of impact identified by concept-coding semi-structured interviews with staff members of the Department of Biotechnology of TU Delft.

#	Quote	Interviewee	Translated
	Enabler		
E1	I think one part of the impact is how you sell it, how you can promote this discovery.	P1	No
E2	When it will be really impactful is when you will integrate that into a cell that goes to a process, and then you can demonstrate that it has an added value.	P1	No
E3	In terms of impact, there is a kind of a notion of PR, so to be able to make a larger audience aware of what you are doing and to communicate properly … and tell them what's the added value of what you are doing.	P1	No
E4	That [having a reputation as a scientist] is also a very important aspect yes. I think it is easier if you are, if you have a reputation already.	P1	No
E5	…the quality of the work…	P1	No
E6	…the trust you have in your data…	P1	No
E7	I always enjoyed inspiring supervisors. An inspiring boss, I always had fun with bosses with which you could do whatever you want, and not checking too much on the daily progress,	P2	No
E8	…being convincing, you know when I started my research area, I was actually the only one worldwide, there was no one else doing something comparable, so you also need to convince people that this is cool. That this is interesting to work on.	P2	No
E9	…to let a post doc go, and or you know, not only a post doc, but my former PhD students are now post docs themselves somewhere else … / … to give them all the freedom to do whatever they like.	P2	No
E10	…it also has time to be used and known	P3	No
E11	…It is really PR	P3	No
E12	Now things have changed, you know it's about Twitter, and all this tools, so at the time I didn't do it, and I don't think anything special contributed, only that the standard channels that we use, and also of course publishing in good journals, …, I think that helped, the fact that our work was already recognized when we wanted publish it by the editors, and were in good journals, that definitely helped, that is no mystery, and nowadays, we would publish much more with Twitter and other channels to make sure that, LinkedIn even, that we have more impact.	P3	No
E13	…we produce really high-quality results, data, and we are acknowledged for that.	P3	No

#	Quote	Interviewee	Translated
E14	[It had this impact] because I was the first one that showed it was possible.	P4	Yes
E15	Interviewer: Do you use that network often to spread new findings, and does that come in handy to make an impact? Yes of course, through this you can test things, so you can also see what others are doing, you can also submit your own things to them, you can sometimes try to do things together to give it all a push in the right direction.	P4	Yes
E16	Collaborations…	P4	Yes
E17	…good people…	P4	Yes
E18	…a good idea of course…	P4	Yes
E19	…you have to become enthusiastic about it yourself…	P4	Yes
E20	…to make an impact you have to be convinced of what you are doing.	P4	Yes
E21	…that you have the sensitivity to pick up questions in your network and to strategically convert them to the right question in the right projects and to get funding for this. In that manner you can realise impact that is bigger than when you're not consciously doing that.	P5	Yes
E22	If you want to set up a whole new system it will take a longer time, this is because a lot more parties are involved and thanks to the involvement of all these parties resistance could arise, whereby things just, for whatever reason, can't land. You need to understand those resistances in order to let those things land.	P5	Yes
E23	If you don't explicitly question an assumption you can surpass yourself, and often the failure, the not embedding of a technology, relates to this assumption… / … so a technology that you reject at first instance, can maybe, in a certain context, be a better choice when you take context variables into account.	P5	Yes
E24	Well you have a responsibility to look outside of the boundaries of your discipline, if you want to realise impact.	P5	Yes
E25	You often see that people that win a Nobel prize, or are awarded Spinoza prizes, just have a bigger involvement in how society works, 'what can I contribute', and simultaneously if you work on one discipline specifically or one principle, and if you open that up for others that surround you, and you don't make a point about those others thinking about it, if you want that to happen, that could also be a form of impact.	P5	Yes
E26	And at the same time, you have to learn, and see and realize, the gaps in the knowledge that exists…	P6	No
E27	Well the most important thing about publishing is that the people to whom this is potentially of interest read it, and see it, so it should be published in a journal that is generally read by everyone and that potentially has the interest in this and then, so that is the first and foremost point, and then of course if you look at the range of journals, then you aim for the one with the highest impact yes. But that is not the foremost target.	P6	No

#	Quote	Interviewee	Translated
E28	I don't think you can convince immediately with the data; you need to present it. You need to present it of course, probably not only in one article, you need a series of scientific publications, I would say, to convince people. Then of course you present it in conferences, and discuss it, and then it becomes believable.	P7	No
E29	…impact is also a function of the persuasive skills, I think, of the researcher. The way you present it as well.	P7	No
E30	…I think that it is important, awareness for grand challenges…	P8	Yes
E31	…secondly, the willingness to take a personal role in this, but also the openness for others to contribute to this solution as well, so to be more of a 'team player' than an 'individual player' is of great importance, I think. An 'individual player', I believe that they are just going to become less interesting in the scientific world.	P8	Yes
E32	Interviewer: …and would they need to be multidisciplinary? Yes, well not per se, but in general more aspects of a problem should be looked at, it is often not only the technical side of a problem that needs to be tackled.	P8	Yes
E33	The projects need to be fundable, so they also have to work out from an economic perspective.	P8	Yes
E34	And the cohesion, well you know, I don't have to get know that [the details], but you do need to know that you are meeting with the right person [that does know the details].	P8	Yes
E35	Looking at these grand problems from multiple perspectives is better.	P8	Yes
E36	I think it is partly the place where we are situated, that we are a biological group within a technical context. Most biological groups have no idea, or well no, not a lot of understanding of technology, reasonably naïve, so the environment we're in of course helps, quantitatively oriented.	P9	Yes
E37	Another thing is, I mean, a lot is happening within 'water', the organizational structure within the Netherlands around wastewater, to have water boards, helps a lot with innovation.	P9	Yes
E38	Well that is simple, if something is better you don't have to put in a lot of effort. So if you, mobile phones were also just unrolled without any large scale programmes like 'how are we going to unroll mobile phones' or 'how do we do this', politics barely interfere with that, it is just a better technology.	P9	Yes
E39	I mean, we perform research, for example for [invention], because we are interested in how bacteria make structures, and why they make structures. And if you know how to make them, and you know the problems within the field, then you can translate this to an application.	P9	Yes
E40	So to take the feedback at the start, in the early stages, to heart, and don't think that somebody is just stuck and comes up with old ideas, I mean it is partly true, because change is not easy, but often if you just continue asking questions you can discover if the ideas are conservatism or if they are indeed arguments, and then you have to solve them.	P9	Yes

#	Quote	Interviewee	Translated
E41	Finding the right partners is always important, …, if you are looking for the right partners, it is not finding the right company, of course the right type of company, but mainly the right person. In order to achieve something when working together with a company, you need to find someone within that company that dares to step into the manager's office. So people in your regular network, a lot of people that work here at the TU that would not dare to wait in front of Tim van der Hagen's office, and say: 'Hey, I have something, and you need to listen to it now'. So, within those companies, you need to find someone, otherwise it will just get stuck in the bureaucracy of the company.	P9	Yes
E42	…of course you need to be careful that you have the right students, that you have motivated students who work on nice projects, that they acquire these skills, it is like training on the job.	P9	Yes
E43	…you have to write articles, you have to communicate the things you find, but you should not maximise this, you have to optimise this.	P9	Yes
E44	…be open for 'coincidental ideas', things that you encounter, famous term: serendipity, and that as a scientist you should recognize the start of possible applicability at a very early stage. This concept requires you to expose yourself, I think, to industrial environments once in a while. It is very difficult to only look from an academic perspective and to make a realistic estimation of what is worthwhile to patent or is possibly applicable. By frequently being in contact with colleagues in industry, you can develop your sense for that a bit more.	P10	Yes
E45	…second is to expose yourself to more application-inspired environments, and I think that the following is important, to be very realistic in what you can do within a university, and when the moment is there to let industry carry out further development.	P10	Yes
E46	Then you enter another domain, that is public-private partnerships. That is quite a hobby of mine, and I think that the key term there is 'complete transparency', towards each other and about the goals of the research.	P10	Yes
E47	Another difference is the time spans, we [universities] often think in blocks of promotion project, at most a two-year post doc project, and then we're talking about a time span of between 2 and 4 years, 4 years for a regular promotion project. For industry a time span of 3 months is sometimes already quite long. Those things should not be brushed away when being in contact with companies, but should be explicitly stated, and then a solution should be sought that does justice to you, the wishes and the urgency of both parties to stay yourself, all while being able to do good research.	P10	Yes
E48	In such a project the continuous re-evaluation of the goals during the project is extremely important.	P10	Yes
E49	It is good to recognize the fact that this concerns different contexts, different organisations and to always keep an eye out for that.	P10	Yes

#	Quote	Interviewee	Translated
E50	Now the other, that is, if you want that inventions to enter the market, then you get to protection of results. And this will only succeed if you go about this very contentious. This also requires a certain mindset; you have to be prepared to do that. Sometimes this creates some friction with, well that depends on the person, but for some scientists this creates friction with their feeling of 'I want to disseminate everything now', when you're in the process of getting ideas, or concepts, to the market. Then you should operate very carefully, until all findings are patented, this is even more important when you work together with industry, and you're also exposed to company secrets. It requires a sort of professional attitude.	P10	Yes
E51	…the search for how to best support people in their own growth, well that is a new road of discovery every time. Going in this road of discovery together, and be transparent in that, and to be honest while not being discouraging, in fact the opposite, to encourage people, but also name the points of development and undertaking action for those. That is very important.	P10	Yes
E52	And that brings me to the subject that could very well be the most important, and that is that there should be a personal dimension in the education of people.	P10	Yes
E53	Well that depends on things like, where the plant is situated, what kinds of regulations are involved, and what the product is. If you change something in a pharmaceutical product that will take longer, since more regulations are involved.	P10	Yes
E54	Well, I think it would be very pretentious and maybe even arrogant, if we [scientists] would say at this moment what the value of an invention is in 10 years. And that is why I think that it is very important that we developed various things in parallel with an open mind. To supply society with many options and the context will subsequently select for options that are actually effective.	P10	Yes

Table 13. Barriers of impact identified by concept-coding semi-structured interviews with staff members of the Department of Biotechnology of TU Delft.

#	Quote	Interviewee	Translated
	Barrier		
B1	…you have several hurdles, you need to be known in the scientific community, to prove that there if you have recognized that, then you can start to go forward and to get a larger audience.	P1	No
B2	…also, public interest, it's always a two-way process. You can get something very interesting, but that doesn't interest your audience, but there you need to have some feedback, you need to have people interested, I think. One of the things that seems to be recurrent in this discussion is education of the audience. Well, all the discussion of GMOs and stuff like that, it's always, because people are not educated enough, they don't understand.	P1	No
B3	So, I'm a bit concerned that I am wasting too much time on chasing for an impact that is a virtual impact or so. Numbers, h-index or things like this. I think this, I think if you would interview me in 10 or 20 years maybe then I'm going to say how much time did I waste there.	P2	No
B4	The problem is, because we work with this complicated tool, we have had a very hard time, having our paper accepted in journals, that are broader, and are more towards cell biology, because that is what we studied. But we really hit a wall where we started to publish that, and we tried to minimize the talk about [invention] as much as we could.	P3	No
B5	So, we've been struggling, so for us the block is really getting our work accepted by a community, that just didn't want that, was not open, or was afraid, or didn't get it, so we couldn't get there.	P3	No
B6	…it is difficult to get funding for that.	P4	Yes
B7	…or we were not able to perform experiments as well as needed to be done to give an answer to that question.	P4	Yes
B8	… it implies that if you're only active within your discipline, so you're only working with, I don't know, the conversion of a certain enzyme and what this enzyme looks like, your impact is per definition limited.	P5	Yes
B9	…if you don't have people to push this technology to believe in it.	P7	No
B10	Interviewer: So, the communication about the project is very important? Yeah definitely the communication is important. It is. I'm sure there were many great ideas that just died because of they were not well known, or they were published in obscure journals or so.	P7	No
B11	…well simply, because in our approach we took an insufficient amount of cultural factors into account that could also play a role there.	P8	Yes
B12	…in other countries the organization is different, and it is more difficult to present new ideas.	P9	Yes

#	Quote	Interviewee	Translated
B13	In many countries water management or waste water management is organised by the city, and the mayor is not interested in improving waste water treatment per se…	P9	Yes
B14	Well, now of course I speak from environmental biotechnology, but it holds true for other areas as well I think, that people often like to think one dimensionally about advantages of new technology, and well, that is very easy… And that is, 'it is so nice, everyone should use it', that is the fascination, and then they forget that it also costs money and there are people who are not interested. And because of this, negative aspects are passed by to quickly during the design…	P9	Yes
B15	Well when you're designing you know this [negative aspects] in quite an early stage. So if you don't take that intrinsically along in a design, then you know you'll run into problem later, for example during the introduction, this is often the case with things. People often forget what it is going to be used for, and people think, well it is good for X, and that is all fine, but the negative aspects get neglected, and then you encounter societal resistance. Or the costs are just too high…	P9	Yes
B16	People of course learn, especially in project proposals but also in other investigations too, to emphasize positive aspects. And often they become 'blind' to the negative aspects, and just do not want to acknowledge them. Well, you should know the negative aspects, because you can solve them.	P9	Yes
B17	There are some aspects that don't benefit the implementation, that is one, that there is no unique advantage, despite what I just said, but that is not unique enough to say, 'we want it'. The invention is actually stuck in the engineering world.	P9	Yes
B18	So involving the right market partners is/was probably the limitation for [invention], it is a limitation, not the limitation, but still a limitation.	P9	Yes
B19	Having a good unique characterization [lack thereof] is also a problem there.	P9	Yes
B20	Also, with the partners there should be someone in the company that can radiate the same beliefs, and does not think 'we're innovative, check', 'we're working with a university, check'. And of course there is a company policy that specifies they should be innovative, and if you're in contact with some that says: 'we have that policy', and strictly follows that policy, but is not intrinsically motivated for the technology so that he would go over his boss, who might say: 'should we spend money on that, etc', and goes to a higher boss to fix things, then you don't innovate as a company.	P9	Yes
B21	Because it is an illusion, a complete illusion, that you can perform applicable research at a university. And that you assume at the start of a development process, at the moment the idea arises, that you can predict what the context is in 5, 8, 10 or 12 years, at which moment you're going to build a plant.	P10	Yes
B22	If we place all our bets on one option, because we're so strongly convinced that that is going to be the magic bullet that is going to solve all our problems, then you'll become very vulnerable for change in that setting.	P10	Yes

Appendix VII – Impact mapping tool design iterations

Presented below are some of the design iterations that led to the design proposal. A table (Figure 17) was the initial concept from which multiple iterations led to the design proposal.

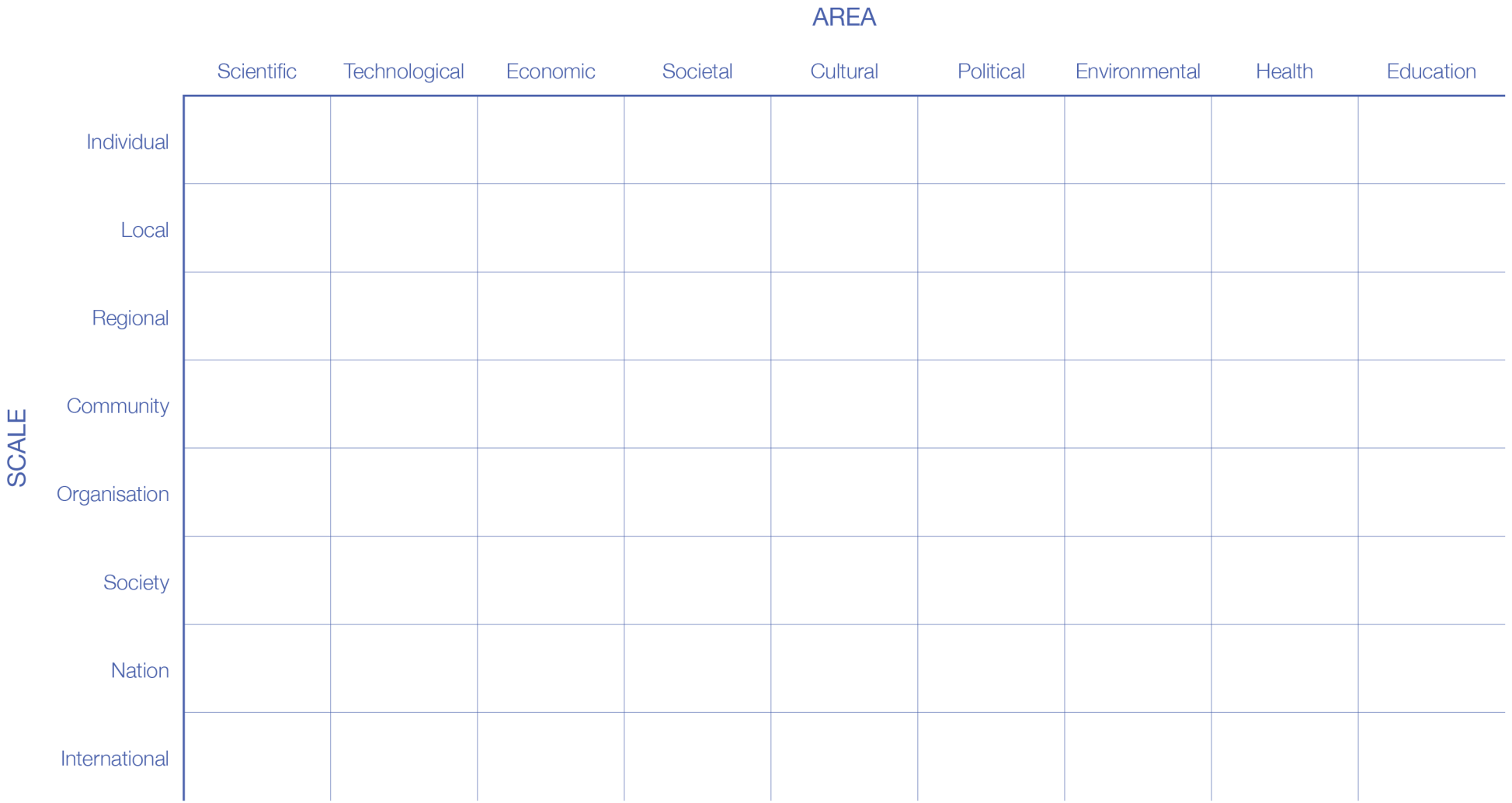

Figure 17. Initial concept design, a simple table to give an overview of impact

A next iteration was a radar plot, showing scales as the dotted lines, and the areas on the axis originating from the centre (Figure 18).

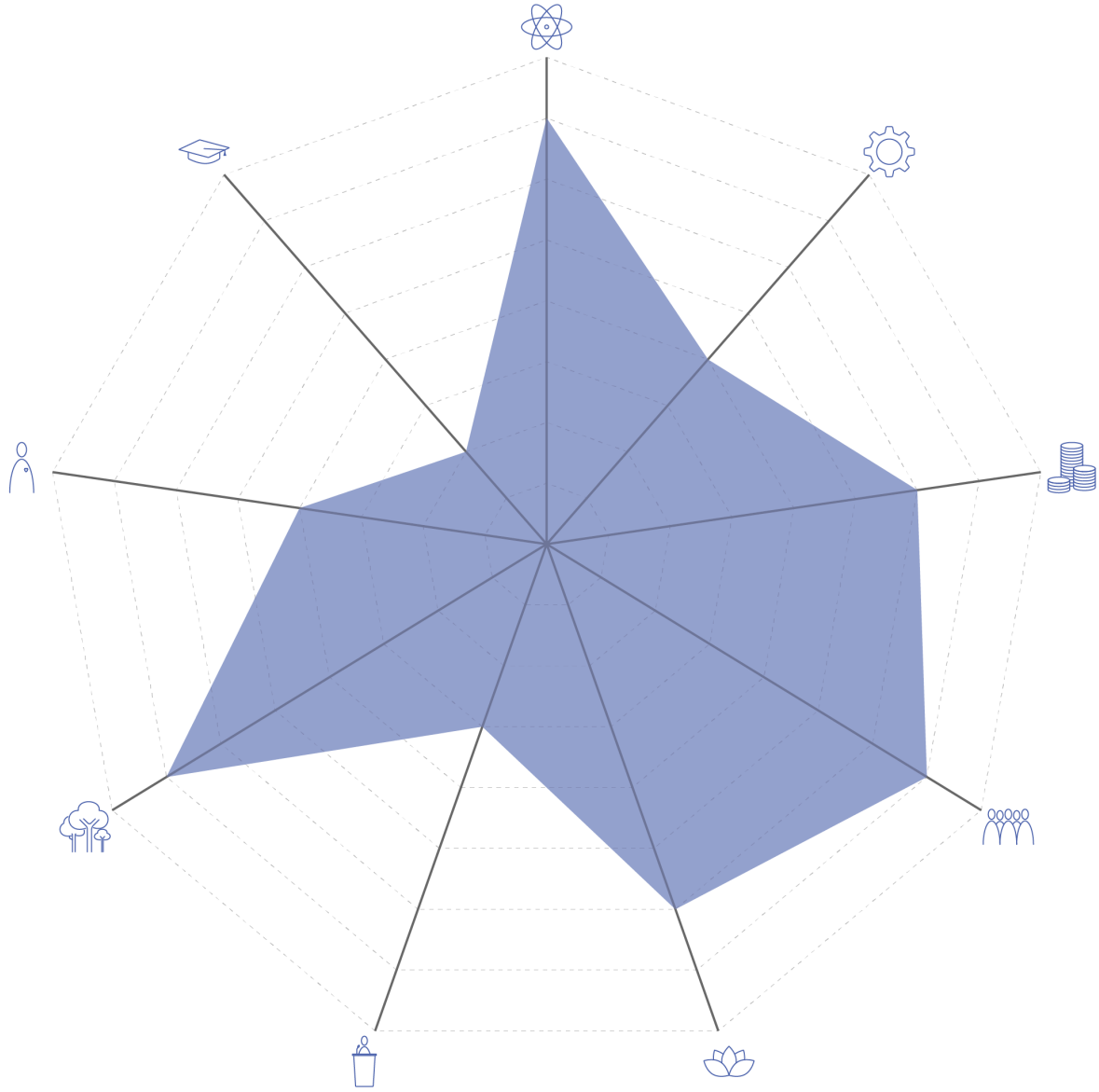

Figure 18. Radar plot for impact.

This would also allow for an overlay between different people. Giving an easy overview of the differences (Figure 19).

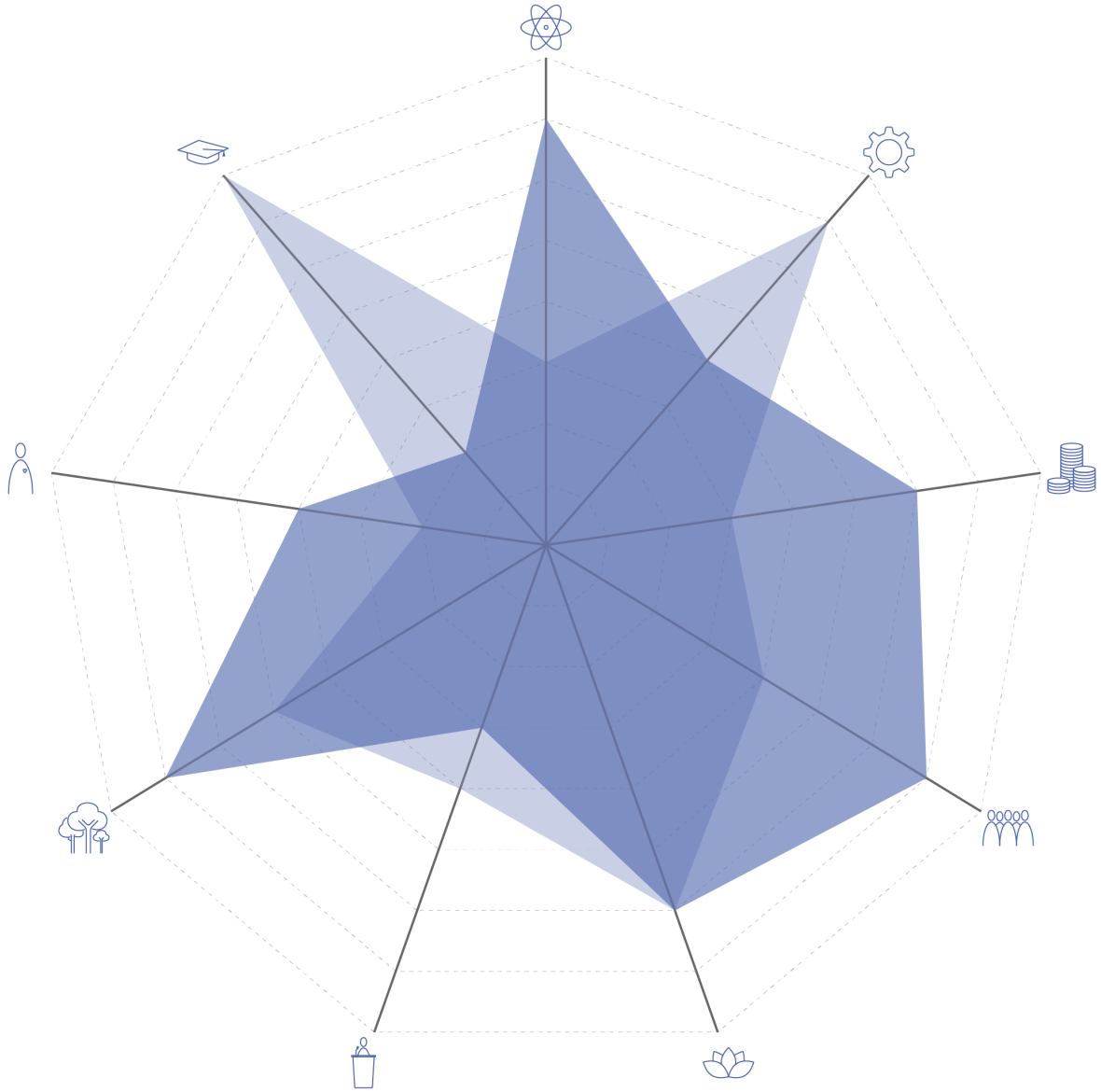

Figure 19. Overlay of radar plots.

This is converted back to the original design. However, this might seem like underlying levels of impact do not matter (shaded in grey) (Figure 20).

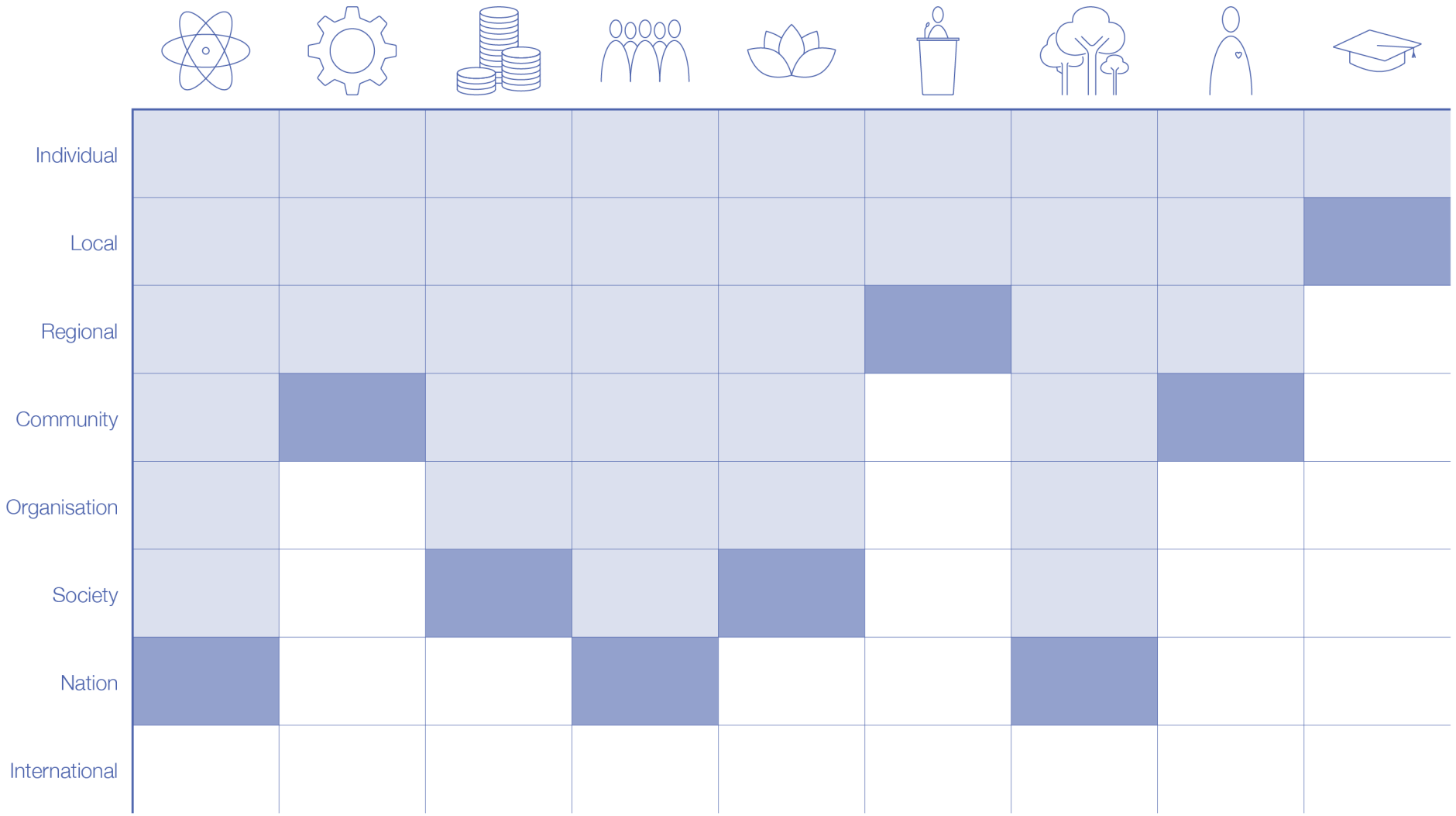

Figure 20. Radar plot domain translated back to the impact table.

Therefore, these are shaded as well. However, the radar plot makes it hard to show these underlying impacts as well (Figure 21).

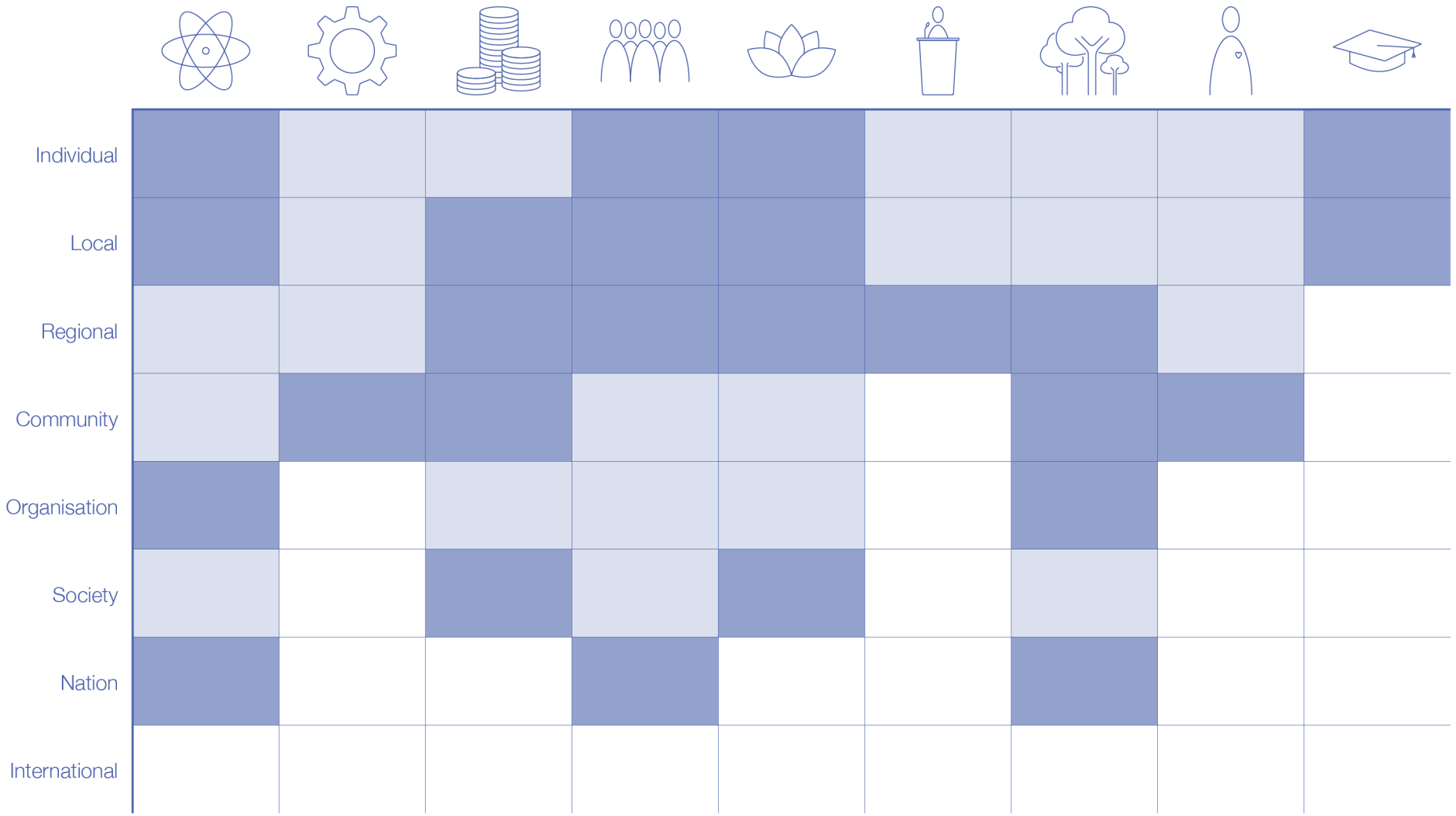

Figure 21. Impact on multiple levels of scale.

Therefore, a simple model with rings surrounding each area of impact, representing the levels of scale, could be used (Figure 22). However, this is not an easy to understand overview of impact.

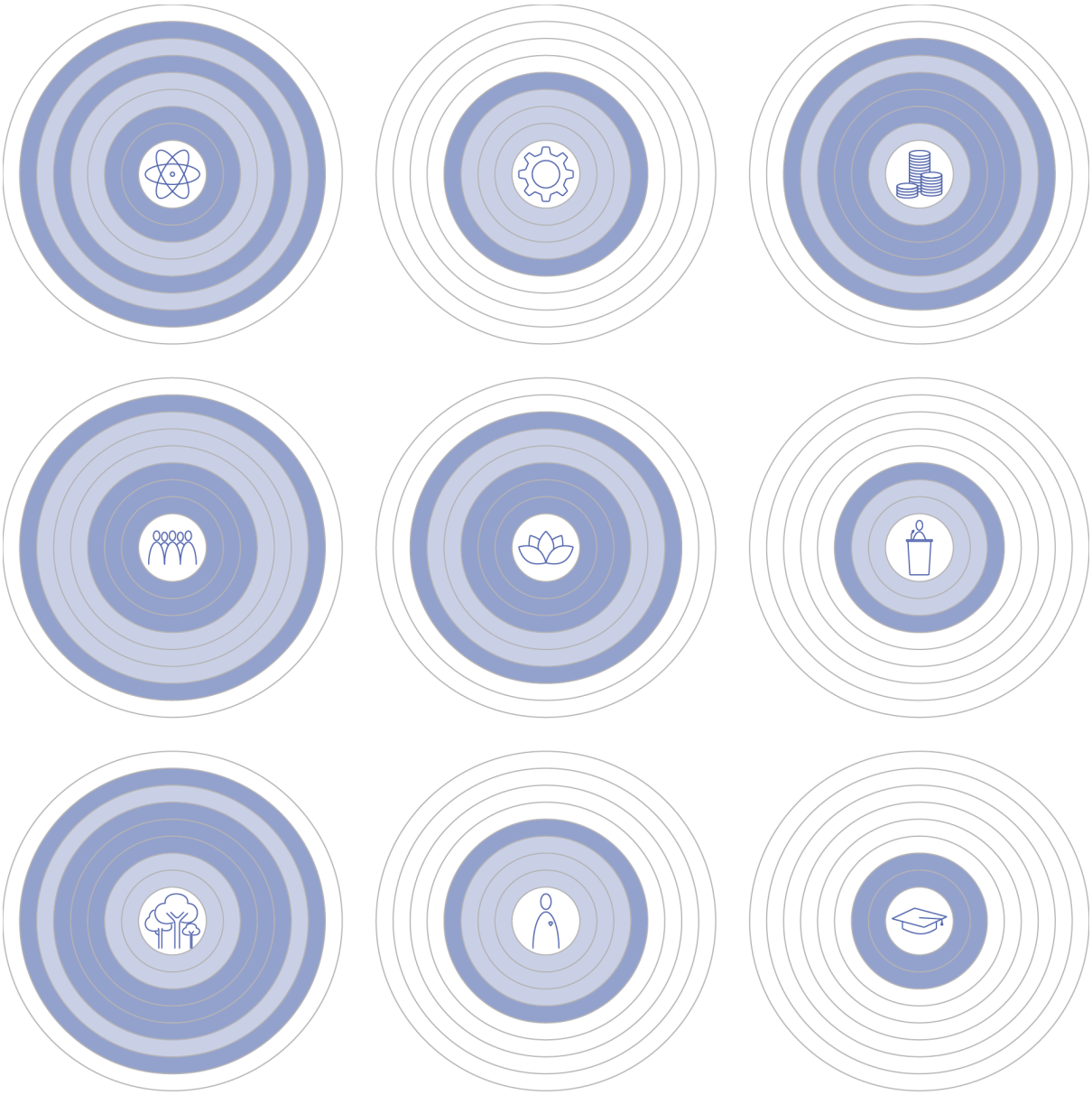

Figure 22. Separate areas of impact surrounded by levels of scale. Dark-coloured rings represent impact filled out in the table; light-coloured rings represent underlying levels of scale with possible impact.

A graph with small and large circles could provide an answer, however, this is still harder to interpret than the radar plot (Figure 23).

Figure 23. A more graphical representation of Figure 21.

The following layout gives a clear overview of all the areas of impact and in which level of scale the impact is found. This design features many harsh, straight lines that form al the coloured cells. In a next iteration these lines could be smoothed out, also making it easier to follow levels of scale around between areas (Figure 24).

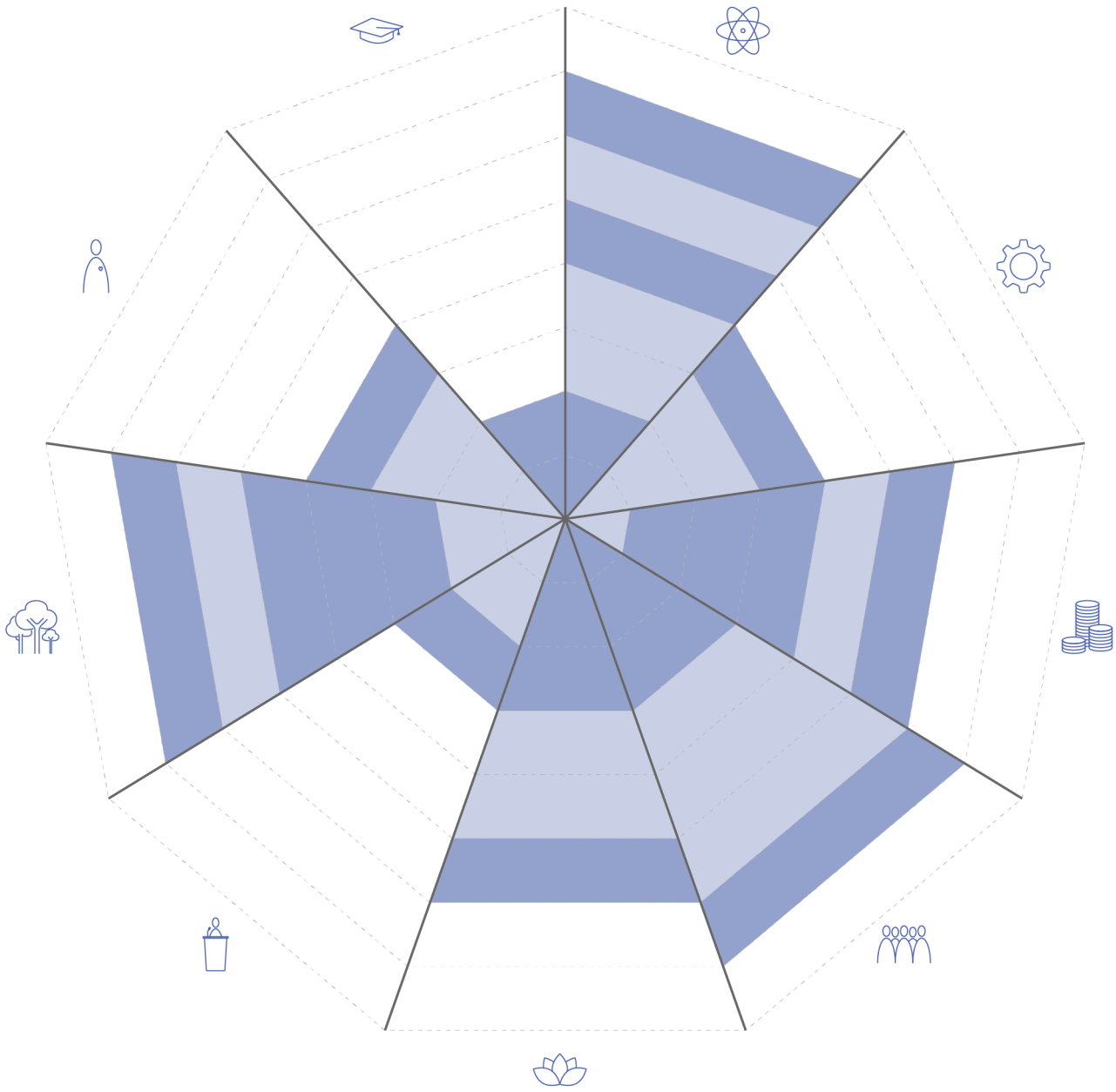

Figure 24. A radar plot with nine sections, showing the impact per level of scale for each of the nine areas of impact. Dark-coloured areas represent impact; light-coloured areas represent possible impact in underlying levels of impact.

This gives an overview that is also easy for the eyes (Figure 25). This design misses a clear indication of the levels of scale and does not place the subject under consideration in the centre. This dealt with in the design proposal as presented in Chapter 4.

Figure 25. Smoothening out the straight lines between areas of impact of the radar plot. Dark-coloured areas represent impact; light-coloured areas represent possible impact in underlying levels of impact.