N5T Task Force on Measuring and Demonstrating Engineering Excellence and its Societal Impact: Benchmark of International Practices

Final Report Presented to the N5T Rectors' Meeting on 3rd June 2014

Task Force:

Aalto University: Dr Antti Saaristo, Development Manager, Policy & Foresight, chair
Chalmers University of Technology: Helena Danielsson, Advisor to Vice-President for Undergraduate and Master's Education
KTH Royal Institute of Technology: Gunnar Ivmark, Senior Administrative Officer, Planning and Evaluation Office
Norwegian University of Science and Technology: Inger-Anne Fånes Sætermo, Senior Adviser, Rector's Office for Education
Technical University of Denmark: Charlotte Holm Billund, Senior Policy Officer, Office for Research and Relations.

Contents:

Summary

Assignment

In the autumn of 2013, the Nordic Five Tech (N5T), an exclusive, strategic alliance of the five leading technical universities in Denmark, Finland, Norway and Sweden, installed a task force to benchmark international practices of measuring and demonstrating engineering excellence and its societal impact. The Task Force was assigned to draft an advisory report on the indicators and approaches the N5T universities could, in light of the benchmarking exercise, adopt for measuring and demonstrating the academic excellence of their engineering research and engineering education and, in particular, for measuring and demonstrating the societal impact – including the value added to companies – of this excellence.

The Task Force was directed to start its work by benchmarking other countries' and other universities' policies in this field. Moreover, the Task Force was particularly instructed to take into account the work on the university-industry collaboration indicators of the Leiden Ranking, although actual bibliometric study was excluded from the work. The Task Force interpreted this emphasis in the assignment to imply that the Task Force was expected to provide advice on devising a perspective to engineering excellence and its societal impact that would succeed in acknowledging and even highlighting the unique excellence inherent in the characteristically Nordic approach to high-quality engineering research and engineering education.

Benchmarks: Main Findings

The Task Force analysed carefully a selection of international approaches to measuring and demonstrating excellence and impact, both at the level of national evaluation frameworks, associations of universities and individual universities. The benchmarking exercise suggests that a partial consensus concerning the central elements of the task of measuring and demonstrating academic excellence and its societal impact appears to be emerging in the international academic community.

General Research Excellence

In the case of general research excellence the international community appears to be converging towards consensus: research excellence is best measured and demonstrated in terms of high-level publications and, in particular, in terms of field-normalised bibliometric citation impact indicators relating to such publications. Indeed, for claims of research excellence to be credible in the eyes of the international community, the excellence should be demonstrable (also) in terms of such indicators.

General Education Excellence

Education excellence is a somewhat more elusive phenomenon. Moreover, indicators of the excellent quality and impact of education are quite often essentially tied to the particular national higher education policy and framework. However, as we argue in the report, also in its case the approaches are converging towards a shared direction emphasising the graduates' employability

and well-structured and well-managed degree programmes, including the retention and graduation rates of the programmes.

Engineering Excellence

A third clear trend emerging from the benchmarks appears to be that although there may be growing agreement when it comes to certain general quality indicators, in most disciplines these indicators capture only a fraction of potential materialisations of excellence: the constitutive elements of research and education excellence vary from one discipline to another, and full appreciation of quality in any discipline requires also discipline-specific approaches to measuring and demonstrating excellence. The general indicators and approaches are indeed too general.

In the case of engineering, there appears to be wide-spread international agreement that the high-quality of engineering design activities, such as the production of artefacts and the design of more optimal processes to meet the needs of users, is an indispensable part of engineering excellence on a par with high-quality scientific publications. Consequently, a serious attempt to measure and demonstrate engineering excellence must be able to recognise excellence in engineering design activities. Engineering design activities feature also as major building blocks of the societal relevance and economic impact of engineering excellence.

The discipline-specific aspects of quality assessment are often seen to call for peer-review to complement indicator-based approaches. While we support this line of thought, our report also argues that quite independently of the question of applying peer-review, the engineering disciplines could and should in any case do a lot more to explicate and demonstrate the aspects of quality and excellence that are characteristic to engineering and that remain somewhat overlooked by the general quality indicators.

Societal and Economic Impact

The benchmarking exercise suggests that there are two different and rather widely applied approaches to measuring and demonstrating excellence in societal impact.

First, Anglo-American universities in particular appear to be keen on presenting calculations to show how investments in a university get channelled to the surrounding region via spending and job creation. This approach, important as it may be, does not touch upon the issue of demonstrating the impact of engineering excellence and thus is not very relevant for this report.

The second widely adopted approach uses as indicators of excellent societal relevance and economic impact such well-known measures as the number of patents and spin off companies, or the amount of external funding from private sources. These are important indicators and they are indeed commonly used by technical universities, national evaluation systems and associations of universities. However, there appears to be equally unanimous international consensus that these indicators (and their variations) nonetheless fail to do justice to the extraordinary depth of the societal and economic impact of excellent academic engineering. In particular, the customary indicators appear to revolve around the impact a piece of research or education had on societal well-being and economic growth without really being able to analyse or demonstrate the nature of the very impact.

Case Studies to Complement the Conventional Indicators of Excellence

The realisation that the excellence indicators fail to capture essential aspects of excellence and impact has led many leading actors in the field to construct schemes for documenting in a systematic way the trajectories of research-based ideas from basic research to commercialised (or e.g. educational) innovations and finally to the impact of these innovations to general well-being (be it societal, health-related, economic, environmental, value added to companies etc.). The documentation takes typically the form of a case study that is reported by using a well-structured template.

The use of case studies has several advantages. First, if the documentation template is well planned, then – by describing the design element inherent in engineering research and education – the case studies complement in an important manner all the excellence indicators and not only indicators of societal and economic impact. Second, the fact that scientists themselves are typically offered the opportunity to document the long-term faith of their research ideas not only ensures that all the relevant aspects and implications of a research or education project are aptly taken into account, but it also contributes to creating a culture where scientists become more aware of their own responsibility to promote and document the impact of their work. Third, a systematic scheme of collecting such case studies forms a highly valuable database a university can utilise in many ways to demonstrate and communicate its societal and economic impact. Such a database at the N5T level would also offer interesting material for science and technology studies. Fourth, documented case studies explicate the impact element of academic engineering exposing it to the criticism and acclaim of the engineering community and beyond; this can be seen as loosely analogous to the peer criticism of scientific publications. Moreover, peer-review committees may be invited to evaluate the case studies. This approach enables a much more comprehensive analysis and evaluation of academic quality and impact than the exclusive use of customary indicators.

Highlighting the Nordic Model of Excellence

A growing amount of evidence suggests that there is a distinguishable Nordic model of engineering excellence (the same approach appears to characterise also e.g. Dutch and Japanese universities of technology) that is based above all on close, long-term and deep cooperation between universities and industry both in research and in education. International peer-review committees are frequently amazed and impressed by the manner in which industry collaboration in research and education is organised in the Nordic universities of technology: it is not only or even primarily a matter of ideas and findings being swiftly transferred from the universities to businesses but rather that the two spheres are largely integrated into close and mutually fruitful cooperation and collaboration. This is widely seen as a unique asset and competitive advantage of the Nordic universities of technology even in the world scale. Similarly, the Leiden Ranking's analyses of university-industry collaboration portray the Nordic universities of technology among the world leaders in this aspect.

Hence, the Nordic universities of technology are particularly able to serve as central links and attractors in innovation ecosystems and networks: their activities integrate the curiosity-driven interests of the international scientific community with the needs and contributions of business,

public sector agencies and third sector organisations into a seamless cooperation and collaboration network particularly well. However, this Nordic strength is such that it may easily remain invisible in the eyes of the conventional excellence and impact indicators that are typically borrowed from basic natural sciences, life sciences, bio sciences and medicine. The Nordic strength operates in the area that is widely recognised both as important and as one easily missed by indicator-based evaluations.

This means that as leading Nordic universities of technology, the N5T universities have a particular incentive to promote a wider appreciation and recognition of excellence in engineering; an approach to excellence that, in tandem with the advanced use of the traditional indicators,

(i) acknowledges engineering design activities as integral elements of engineering excellence
(ii) grants high societal and economic relevance and impact a similar status as a fundamental constituent of engineering excellence and
(iii) highlights deep collaboration with external partners (both in engineering design projects and in foundational research leading to high-quality scientific publications) as a major asset in the quest for engineering excellence and societal impact.

Recommendations

The detailed conclusions, suggestions and recommendations of the Task Force are introduced in the report. The five main conclusions emerging from the benchmarking exercise can be summarised as follows.

First, when it comes to measuring and demonstrating research and education excellence, the N5T universities should ensure that the excellence is visible also in terms of the widely accepted, by now familiar quality indicators. Only this gives international credibility to claims of high quality and world class excellence. The same applies to the use of the received indicators of societal impact.

Second, the unique strengths of the N5T universities belong to the area that is generally accepted both as a important, constitutive element of engineering excellence and as the blind spot of traditional indicators: research-based engineering design, integrated collaboration with businesses and deep embededdness in innovation ecosystems, high societal relevance and long-term economic impact. Thus, the N5T universities should focus on explicating the role of the N5T universities in innovation networks and, in particular, on making the societal and economic impact of the N5T universities' research and education as visible as possible to policymakers and the general public at large. Documenting and highlighting the results and outcomes from the N5T universities is crucial to ensure that public investments in R&D in the Nordic countries remain at the high level and that the technical and engineering sciences receive the high share of the R&D spending they deserve.

On the basis of the benchmarking exercise it appears that the main method for fulfilling this second aspiration might well be a well thought-through documentation and use of case studies of high societal and economic impact of engineering research and education. The N5T universities should think of defining a joint template for documenting and reporting such case studies. The templates used by e.g. the British Research Excellence Framework or the Russell Group of leading British research universities could offer a fruitful starting point for this work, but ideally the

template should highlight the shared Nordic values of the N5T universities, such as sustainability, collaboration, internationalisation, innovation and excellence. Both the leadership and the academic community of the N5T universities should be well represented in the process of defining the template.

Third, when it comes to demonstrating and promoting the social and economic impact of engineering excellence, the N5T universities should review what possibilities there are for speaking more with one voice to policy makers, industries and the public at large. Indeed, in the Nordic countries the N5T universities could adopt a role somewhat similar to the role the Russell Group universities have in the UK: the N5T universities could publish joint reports on the impact of the N5T universities (building on the systematically documented case studies) that also include policy recommendations. There could also be, for example, an annual N5T conference on the impact of research and education in engineering and a specific impact award; all these kinds of activities would certainly gain weight from being joint N5T activities.

Fourth, the Nordic societies with their well-developed and open statistical and economic data sources would make the economic impact of the N5T universities a particularly suitable object for scientific, e.g. econometric, studies. The Technical University of Denmark has already conducted two impact studies on the productivity gains of businesses associated with (i) R&D collaboration with the University and (ii) the hiring of engineering graduates from the University. The N5T universities might wish to consider a joint effort as well as supporting scientists to adopt a wider, Nordic approach to this cluster of research possibilities.

Fifthly, the N5T universities could perhaps approach e.g. the Nordic Council of Ministers to gain support and visibility to the task of explicating and demonstrating the notable excellence and extraordinary impact of Nordic academic engineering.

1. Introduction

1.1 Background

Evaluation of the quality and impact of university research and education are becoming constantly more prominent and affect increasingly the operational environment of universities. However, the indicators applied in such evaluations are typically borrowed from the basic natural sciences, life sciences, bio sciences and medicine. In particular, the indicators are largely inadequate for the engineering sciences: they fail to acknowledge essential aspects of engineering excellence and, in the case of the aspects of engineering excellence the indicators do capture, they tend undervalue certain characteristics of engineering, such as the context-specific nature of research and high-level of multi- and interdisciplinarity. In sum, the conventional indicators (i) recognise only a small (albeit crucial) part of engineering excellence and (ii) evaluate that part in terms that are arguably somewhat unsuitable for engineering.

Thus, universities of technology feel the pressure to devise new methods for measuring and demonstrating engineering excellence and, in particular, the remarkable impacts engineering excellence, both in research and education, generates for societal and economic development. The Nordic Five Tech (N5T) universities are particularly well suited for joining forces to tackle this challenge. The five member universities are the leading universities of technology in the Nordic countries, and the fact that the universities come from four different countries allows the N5T to distance itself from the debates relating to the details of the national evaluation systems and resource allocation mechanisms of each individual country and to strive for a more general picture. However, the operational environments in the Nordic countries are sufficiently similar to allow the member universities to speak with one voice and to outline a shared, distinguishably Nordic approach to measuring and demonstrating engineering excellence and its societal and economic impact.

Building on this background the Rectors' Meeting of the N5T universities decided in the summer of 2013 to set up a joint Task Force for preparing ground for a shared approach to measuring and demonstrating engineering excellence and its societal impact. The task of compiling the Task Force, and of defining its exact assignment, was delegated to the N5T Education Committee.

1.2 Task Force Members

The N5T Education Committee appointed Dr Antti Saaristo from Aalto University to chair the Task Force and invited the member universities to appoint a representative from each university to the group. The core group consisted of the following members:

- Aalto University: Antti Saaristo, Development Manager, Policy & Foresight, chair
- Chalmers University of Technology: Helena Danielsson, Advisor to Vice-President for Undergraduate and Master's Education
- KTH Royal Institute of Technology: Gunnar Ivmark, Senior Administrative Officer, Planning and Evaluation Office
- Norwegian University of Science and Technology: Inger-Anne Fånes Sætermo, Senior Adviser, Rector's Office for Education

- Technical University of Denmark: Charlotte Holm Billund, Senior Policy Officer, Office for Research and Relations

In addition to the core group members, also Alexandra Priatna (Chalmers University of Technology) and Kristin Wergeland Brekke (Norwegian University of Science and Technology) contributed in a crucial manner to the work of the Task Force.

1.3 Assignment

The N5T Education Committee assigned the Task Force to prepare ground for a possible larger project of devising shared N5T indicators for measuring excellence in engineering (in particular, long-term impact) by benchmarking the best practices that international evaluations, organisations and universities currently apply for measuring and demonstrating engineering excellence and its societal impact, including the value added to companies. The Task Force was specifically instructed to take into account the work of the Leiden Ranking on measuring the university-industry collaboration.

Thus, the Task Force was not requested to measure or demonstrate the engineering excellence and impact of the N5T universities but rather (i) to explicate guiding principles of the conceptual frameworks within which such measurements and demonstrations take place and (ii) to draft an advisory report offering suggestions concerning the possibilities the N5T universities might have for devising a shared framework for measuring and, in particular, demonstrating the (especially Nordic) strengths in engineering excellence and its societal and economic impact.

1.4 Work Methods and Procedures

The N5T universities appointed the Task Force members in the beginning of December 2013 and the Task Force met at Aalto University on 11th December 2013 to define the work plan for the Task Force and to agree on the specific benchmarking targets and the division of labour within the group. The work plan was the presented to the N5T Education Committee on 4th February 2014 and revised on the basis of their comments.

The Task Force decided to focus on the following benchmarking targets:

National Evaluation Frameworks:
- Australia
- the Netherlands
- UK

Associations of Universities:
- American Association of Universities
- Finnish Universities of Technology
- Russell Group
- Universities UK

Individual Universities:
- All the N5T universities

- Delft University of Technology
- Eindhoven University of Technology
- ETH Zürich
- Georgia Institute of Technology
- INSA Lyon
- RWTH Aachen
- University of Tokyo

The three national evaluation frameworks were selected for the reason that they are generally considered to be international pioneers in the evaluation of excellence and, in particular, societal impact of science (particularly research). Any new approach in this field must take into account the work carried out in these countries.

The American Association of Universities and the Russell Group were selected as benchmarking targets, because they are associations of leading research universities in North America and the UK (respectively) and as such their activities in promoting the excellence and impact of research and education could be seen as possible models of the approach the N5T universities might adopt in the Nordic countries. The Universities UK is another pioneer in promoting the impact of university education and as such was naturally included in the benchmarking exercise. Finally, although the Finnish Universities of Technology do not form a formal group, the fact that the universities have adopted a shared approach to evaluating research excellence and impact makes it possible to use this informal assembly to pinpoint certain characteristically Nordic features in engineering excellence.

The N5T universities ended up on the list of benchmarking targets when the Task Force members realised that the manner in which the individual N5T universities measure and demonstrate excellence and impact is not common knowledge in the network. The Education Committee had also emphasised the importance of the Leiden Ranking's work on measuring university-industry collaboration and, in addition to the N5T universities, the Dutch universities of technology as well as Japanese universities appear to do particularly well in that ranking. Thus the Task Force decided to study also the approaches of Eindhoven, Delft and Tokyo. The Dutch universities operate in an environment in many ways similar to the Nordic environment, which again made the Dutch universities particularly interesting benchmarking targets. The Education Committee also instructed the Task Force to look at suitable American, German and French institutions, which resulted in including Georgia, Aachen and Lyon in the list. Finally, as a leading European university of technology also ETH Zürich was included in the list.

The Task Force aimed to benchmark the way in which excellence and impact is understood in these benchmarking targets and to list the actual indicators these instances apply. The benchmarking was carried out by studying carefully the webpages of these organisations, their relevant published reports and, in some cases, by contacting the relevant offices of these institutions. However, the Task Force observed rather great variety in the ability and willingness to communicate the approach and indicators to the Task Force. Consequently, the results of the benchmarking exercise are neither comprehensive nor fully commensurable, and the Task Force decided not to include the benchmarking results as such in this report. Instead, the present report describes and analyses certain selected findings from the benchmarking exercise to justify the

conclusions and recommendations presented in this report. However, the benchmarking results are available on request for internal use for e.g. the indicator designers of the N5T universities.

The Task Force met for the second time on 14th May 2014 at Chalmers University of Technology to discuss and analyse the findings of the benchmarking exercise and to define the main conclusions and recommendations the Task Force presents in the present report. The structure and main contents of this report were also agreed on in that meeting.

Finally, the N5T secretariat invited the Task Force to present its main points in the N5T Rectors' Meeting at Chalmers on 3rd June 2014, and the Task Force decided to deliver this written report to the Rectors on the same day.

2. Excellence and Impact in Engineering: General Approaches

This Section discusses the main findings and conclusions emerging from the benchmark of national evaluation frameworks and associations of universities. A major lesson is formed by the observation that in the case of engineering, the accepted view appears to be that a comprehensive understanding of excellence must be able to acknowledge the practical or applicability-oriented dimensions of engineering: Any serious attempt to measure and demonstrate excellence in engineering cannot neglect the design aspects of engineering, for these aspects are arguably essential for a discipline to count as an engineering discipline. To put it roughly, where basic science seeks to reveal the nature of reality by producing true or at least reliable statements about the reality and its processes, design disciplines apply this basic scientific knowledge to reshape the reality (in a manner that is of value to users) or to create artificial environments where e.g. the causal agents are limited and well controlled.

The design element plays a crucial role in a number of disciplines ranging from art to software engineering, from law to architecture. In engineering the design element takes typically the form of designing new technological artefacts, which can be products or processes and take either the physical form (such as bridges, mobile phones, chemicals or power plants), the form of abstract algorithms (software designs etc.) or services (such as internet transactions). Many interesting engineering design artefacts combine all these forms and more (virtual realities etc.).

This report does not aim for a comprehensive analysis of the nature of engineering. For the present purposes it suffices to acknowledge that engineering contains essentially a design element: the application of scientific knowledge to create new artefacts that convert resources optimally to meet the needs of users. A full appreciation of excellence in engineering must therefore be able to appreciate the excellence inherent in such conversion processes and design products (this is even more important in the case of the societal impact of engineering). However, the acknowledgement of excellence in design activities and design products as an essential element of engineering excellence does not imply that the publication of research results in peer-reviewed journals would not be of utmost importance also in engineering.

Keeping this character of academic engineering in mind, let us now turn into some leading frameworks of measuring, evaluating and demonstrating academic (engineering) excellence and, in particular, its societal and economic impact.

2.1 Universities UK and the Impact Studies of the American Association of Universities

Universities UK is the representative organisation for the UK's universities. Its work methods include lobbying and campaigning on behalf of the UK's universities, and the reports and studies commissioned by the Universities UK that seek to demonstrate the critical significance of universities to economic growth, prosperity, innovation, cohesiveness and social change, play a notable role in this endeavour.[1]

[1] See, e.g., Faiza Shaheen, *Degrees of Value: How Universities Benefit Society*, New Economics Foundation, 2011 and Ursula Kelly, Iain McNicoll and James White: *The Impact of Universities on the UK Economy*, Universities UK, April 2014. Both reports are available at www.universitiesuk.ac.uk.

While appreciating the fact that a major part of the societal and economic impact of universities is based on the technological (and other) innovations that the research discoveries at the universities help to generate, when it comes to the impact of universities, the emphasis of the approach in the Universities UK reports appears to be on explicating the often somewhat under-appreciated economic benefits relating to certain outcomes of universities and university education such as social mobility[2] and social cohesion.[3] In a related manner, the Universities UK seeks to estimate the monetary value of the access to cultural resources that the different activities (both "official" and extra-curricular activities) of a university provide for the local community of the university in question.[4]

A somewhat related approach is adopted by the Association of American Universities (AUU), an association of 62 leading research universities in the United States and Canada.[5] Major activities of the association include federal government relations, policy studies, and public affairs. Explicating the economic benefits a research university provides for the university's local environment appears to be a central aspect of AUU's task of demonstrating the economic impact of universities.[6]

In other words, both the Universities UK and AUU tend to portray the economic impact of universities in terms of explicating how the funding received by a university gets channelled to the community by means of the university's activities that require local spending and create jobs as well as other cultural and societal benefits.[7] This is no doubt an important approach to the economic and societal impact of universities. However, this mode is not directly connected to

[2] For example, the Manchester Metropolitan University calculates that it contributes £147.2 million annually to society solely by admitting higher than average levels of students from low-income households and by facilitating their social mobility. See Faiza Shaheen, *Degrees of Value: How Universities Benefit Society*, New Economics Foundation, 2011, available at www.universitiesuk.ac.uk.

[3] According to a study commissioned by the Universities UK, "the public value generated from just three society-wide outcomes – greater political interest, higher interpersonal trust and better health – amount to £212 million from the 1.9 million current undergraduate students and a total of £1.31 billion for all 11.8 million graduates in the UK" (ibid., p. 2)

[4] For example, the report mentioned above (pp. 2-3) estimates that the indirect economic benefits for the local community of a Warwick University voluntary programme of helping 100 students of a local primary school to read more fluently reaches the sum of £290,000 and that the financial value of the cultural benefits the Warwick Arts Centre offers to the local community amount to no less than £27.7 million.

[5] See the AUU website celebrating the economic impacts of AUU universities at http://www.aau.edu/research/article.aspx?ID=9266.

[6] For example, Boston University reports that in 2012 the overall economic impact of the salaries paid by the University, the goods and services purchased by the University, the spending of the University students and their out-of-state visitors and, finally, the additional spending created by this spending, amounted to the total of US$ 1,110,000,000 to the City of Boston, US$ 3,550,000,000 to the Boston Metropolitan Area and US$ 3,890,000,000 to the Commonwealth of Massachusetts, which then translates to the total employment impact of 42 427 jobs to the Commonwealth (see http://www.bu.edu/oir/files/2014/02/Abridged-Economic-Impact-Report-FY2012.pdf).

[7] Or, perhaps partly to justify the hefty tuition fees, how access to higher education entails improved life chances and opportunities, including higher earnings, to an individual: In 2005 in the UK, the average graduate was estimated to earn 23% more over a working life than her equivalent without a university degree; see *The Economic Benefits of Higher Education Qualifications: A Report Produced for the Royal Society of Chemistry and the Institute of Physics*, PricewaterhouseCoopers LLP, January 2005. Available at http://www.rsc.org/images/EconomicBenefitsHigherEducationQualifications_tcm18-12647.pdf

engineering as such and, perhaps even more crucially for the present purposes, is not based on the impact of excellence and the impact of leading quality, at least in any straightforward manner.

Thus, to the extent that the aim is to measure and demonstrate the economic impact and societal importance of top-quality engineering research and education, the approach highlighted by the Universities UK and the Association of American Universities may not be the kind that Nordic Five Tech seeks to promote in the present context. This leads us to turn to the British Russell Group, which is a group of 24 leading British research universities. Accordingly, Russell Group is particularly concerned with demonstrating the extraordinary impact of academic excellence.

2.2 Russell Group

The Russell Group is an association of 24 British public research universities, founded in 1994 to advocate its members' shared interests to government and parliament. In 2010-2011, the Russell Group universities received 82% of the total research funding allocation of the Higher Education Funding Council for England. The Russell Group universities have a particular interest to promote the general appreciation of the importance of high-quality research, including teaching based on such research. Accordingly, the Russell Group works hard to demonstrate the economic and social impact of the high-quality research and education of its member universities.[8]

The Russell Group approach to *the economic impact of research* focuses in particular on the benefits of university research to new and existing businesses. Using well-documented case studies, the Russell Group seeks to demonstrate "how businesses gain competitive advantage through collaborating with universities on research and research-based activities. Working with a university can enable a company, of any size or industry sector, to access the latest knowledge, ideas and research expertise relevant to its business."[9] The case studies of university-industry collaboration the Russell Group offers in the report are meant to demonstrate, in particular, how

1. research-led teaching (especially at the MSc and PhD levels) provides businesses with labour force particularly suited for taking the businesses to the next level
2. many businesses access the research expertise of universities through consultancy aimed at addressing specific business problems
3. research at the universities can support the provision of continuous professional development to businesses
4. the economy benefits from the commercial exploitation of research through licences and spin-out companies.

It appears that there are perhaps two main lessons that the N5T universities could take home from the Russell Group approach to the economic impact of research described by the four theses above.

[8] The key documents here are *The Economic Impact of Research Conducted in Russell Group Universities*, Russell Group Papers 1/2010, available at http://www.russellgroup.ac.uk/uploads/RG_ImpactOfResearch2.pdf, and *The Social Impact of Research Conducted in Russell Group Universities*, Russell Group Papers 3/2012, available at http://russellgroup.org/SocialImpactOfResearch.pdf.

[9] *The Economic Impact of Research Conducted in Russell Group Universities*, Russell Group Papers 1/2010, p. 3.

The first lesson is the importance and usefulness of publishing and advertising interesting and inspiring case studies. Calculating the estimated economic value of a university's research achievements is admittedly important, but highlighting particularly impressive cases by telling an exciting story from research breakthroughs to economic impact may well be even more effective, at least for some purposes. The case studies also make very explicit the role of long-term, curiosity driven research on the background of the most successful licenses and spin-off companies. In the university context, thriving commercialisation requires research environment based on long-term (often decades), continuous investments in basic research.

The second lesson receives its motivation from the somewhat surprising feature of the Russell Group approach to the economic impact of university research, namely that the Russell Group's four main channels of economic impact (introduced above) all maintain or even presuppose the strict conceptual and factual demarcation between the businesses and the academia. Research is carried out at the universities, and the impact on businesses is then achieved by exporting research results or research-based skills and information from the ivory tower to the outside world.

At the N5T universities, in contrast, the approach to economic impact appears to have a slightly different emphasis. The focus is not always merely on building bridges between the separate worlds of the academia and the businesses, but rather on merging the two worlds, on transgressing and dissolving the boundaries between the academia and the businesses. As the Leiden University-Industry Collaboration Ranking (that in 2013 placed all the N5T universities among the Top 10 universities in the world when measured in terms of the proportion of scientific papers co-authored with businesses) testifies, at the N5T universities the actual research is often, or at least more often than in the other universities around the world, carried out in close and long-term (from the definition of research questions to the dissemination of results) cooperation involving both universities and businesses.[10]

At the N5T universities, the definitive model of a university-industry collaboration project is this kind of scientific research project, not the kind of consultancy project directed at a specific business problem that the Russell Group report mentions as one of the four paradigmatic channels of the economic impact of university research. Relatedly, students at the N5T universities are not merely sent to the external world equipped with research-based skills and abilities, but rather they have already during their studies learned to work with real problems and projects of real companies in a manner that utilises fully the possibilities offered by membership in the international scientific community.

This difference in emphasis has arguably rather great significance. The Russell Group itself characterises the economic impact of universities as based largely on the fact that companies, particularly in knowledge-intensive fields, gain clear competitive advantage from working with universities by acquiring direct access to the research expertise and research resources of the international scientific community and by being able to recruit top talent.[11] In other words,

[10] See http://www.leidenranking.com/ranking/2013. Unfortunately the 2014 ranking (http://www.leidenranking.com/ranking/2014) is not as flattering to all the N5T universities, but this setback does not undermine the general observation that the N5T universities have a particular strength in their deep-rooted university-industry collaboration.

[11] *The Economic Impact of Research Conducted in Russell Group Universities*, Russell Group Papers 1/2010, p. 8.

cooperation with universities allows businesses to integrate their activities to the activities of the international scientific community and to be part of the innovation ecosystem that consists of universities, research institutes, public sector agencies, other companies and third sector organisations. Thus, the key word here is integration; surely the approach to university-industry co-operation that characterises the N5T universities supports this aspect better than the approach that builds on the clear separation of the two spheres.[12] The close and deep cooperation with businesses is something that distinguishes the way the N5T universities work from most other top universities in the world and gives the N5T universities a true and rather unique competitive asset even in the world scale.

In addition to the economic impact of research excellence, the Russell Group universities have also sought to explicate *the social impact of research* conducted at Russell group universities, where the aim is "to demonstrate the benefits of research for the nation's health, quality of life, culture and environment".[13] As in the case of the economic impact, also here the main method is to present impressive case studies to demonstrate the impact. Since the focus is on social impacts in the wider sense than mere economic benefits, e.g. on cultural effects and promoting the general quality of life, the impacts discussed in this context are not easily quantifiable. This, in turn, means that the persuasive power of imposing case studies, stories, is even more highlighted in this context.

2.3 The UK Research Excellence Framework

The UK Research Excellence Framework (REF) is the new system for assessing the quality of research in the British higher education institutions. It replaces the UK Research Assessment Exercise (RAE) structure and will be completed in 2014. For the present purposes REF is particularly interesting in the sense that unlike previous RAEs it includes an element that addresses the non-academic, i.e. the societal and economic, impact of research. The REF defines such impact 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".

The basic structure of impact evaluation in the REF follows the methods of previous RAEs: participating institutions submit representative selections of their best research outputs, and a panel of experts (in the fields covered by the panel) evaluates the submissions. In the case of the impact of research, the submission consists of a completed impact template that describes the submitting unit's approach to impact of research and a case study describing the specific impacts of the submitted research during the assessment period. The wider approach described in the impact template is meant to contextualise the particular case study. The expert panels assess the submitted demonstrations of impact by applying the panel-specific assessment criteria for impact. The most relevant REF panel here is the panel B that covers the traditional engineering fields as well as basic natural science.

[12] It should be said that the Russell Group universities are pioneers in creating strategic, long-term research partnerships with major companies. Such partnerships are typically manifested in joint industry-university research centres. However, the Leiden findings show that at the N5T universities the cooperative culture is rather deeply rooted also in everyday research activities of normal academic departments.

[13] *The Social Impact of Research Conducted in Russell Group Universities*, Russell Group Papers 3/2012, p. 1.

Since the REF is a nation-wide and systematic framework for assessing research quality and research impact, and one that has great financial consequences for the participating institutions, the REF has documented thoroughly the manner they understand excellence and impact, and these documents are publicly available.[14] In order to help the researchers to submit their case studies, and to assist the panellists to recognise different materialisations of research impact, the REF documentation gives rather wide-ranging examples of possible modes of impact a piece of research might manifest. The main impact categories applied in the documentation are

- Economic Impact
- Impacts on Public Policy and Services
- Impacts on Society, Culture and Creativity
- Health Impacts
- Impacts on Practitioners and Professional Services
- Impacts on the Environment

Under all these main categories, the REF characterises several ways in which research impact might manifest itself. In assessing the submitted case studies (and the general approach described in the impact template), the panel forms an overall view about the reach and significance of the research described in a submission and rate it on a scale from zero to four stars.

It is clear that the numerical rating is bound to remain rather qualitative and subjective and also relative to the set of submissions a panel assesses. One might even be tempted to conclude that the whole idea of assessing impact case studies with a numerical scale is a rather artificial requirement of the REF context, where the assessment results must be unequivocally translatable into funding allocations. It seems that there is no reason why the N5T universities should introduce a system of rating impact case studies, unless one particularly wants to introduce an REF-like impact element into a formal resource allocation model of a university.

However, what the N5T universities could and perhaps should take on board from the REF approach to measuring and demonstrating the societal impact of research excellence is the systematic fostering of a culture where researchers learn routinely to promote, (self-)assess, explicate and communicate the different forms of the societal impact of their academic achievements. Moreover, the leadership of the N5T universities could follow the good model, created by the Russell Group and REF, of collecting these impact analyses and case studies in a uniform and systematic manner. The possible N5T template for documenting case studies of engineering excellence and impact could, for example, highlight the shared Nordic values of the N5T universities as technical universities, such as sustainability, collaboration, internationalisation, innovation and excellence. Both the leadership and the academic community of the N5T universities should be well represented in the task of defining the template.

The collection of N5T examples and case studies of social impact of research would most likely not offer a basis of a robust statistical or economic analysis, but the material produced in this manner would nonetheless form an exceptionally valuable resource for the universities. The N5T universities could, for example, consider publishing a joint impact report in a manner of the Russell Group reports, where inspiring case studies would provide background and evidence for more general policy recommendations. A regular N5T conference presenting the most impressive

[14] See http://www.ref.ac.uk/.

case studies might also be interesting even for a wider audience. There could, for example, be a special award for a particularly impactful research achievement (awarded by a jury including also the stakeholders of the universities).

2.4 Australia – the Research Quality Framework

Prior to the UK REF, the Australian Research Quality Framework (RQF) was perhaps the most developed national system for recognising, acknowledging, measuring and rewarding the impact of university research. However, the RQF was never implemented, for final agreement concerning definitions and evaluation methodologies was never reached, and the framework was discarded in 2007 and replaced by the Excellence in Research for Australia (ERA) framework.[15] For the present purposes, however, the rise and fall of the RQF is perhaps the more interesting case.

The RQF was an attempt to find well-defined, largely quantitative indicators of research impact. Accordingly, the fall of the RQF meant also that, at least for the time being, the less rigid approach to research impact, building largely on the qualitative assessment of case studies and free-form evidence, appears to have taken the limelight away from stricter, indicator-based approaches.

Even though the RQF was never implemented, it paved way for many subsequent evaluations of research impact. For example, the list of possible indicators sketched for the RQF pointed towards the need to draw a clearer distinction between academic and societal impact of research. Moreover, the problems encountered by the RQF supported the conclusion that there is no unambiguous way of calculating the relative significance of different modes of research impact (and different impact indicators), but that the comparison is bound to remain rather subjective and qualitative. There simply was no common currency for all the suggested indicators, and many of the most central indicators were clearly more suitable for qualitative evaluation than for quantitative calculation. This realisation guided the RQF to recommend the use of expert panels in the impact assessment.

Moreover, it was also understood that the panel assessment would have to be an assessment of a sample of impact outcomes, case studies, and not an attempt to measure the total impact achieved by a university or some other unit of assessment. Both of these realisations or policy definitions feature as the animating principles behind the REF approach to research impact, which has now taken over the RQF's role as the leading national framework for measuring research impact.

2.5 The Netherlands – the Standard Evaluation Protocol 2009-2015

The Standard Evaluation Protocol (SEP) provides the framework for assessing scientific research in the Netherlands in 2009-2015.[16] The units of assessment in the SEP are research institutions as wholes as well as their research programmes. The SEP contains four main criteria: quality, productivity, societal relevance, and vitality and feasibility. The actual assessment is carried out by expert panels that base their assessment on submitted evidence and a site visit.

[15] See http://www.arc.gov.au/era/.
[16] See https://www.knaw.nl/en/news/publications/standard-evaluation-protocol-sep-2009-2015?set_language=en.

Societal Relevance is seen in the SEP to cover the social, economic and cultural relevance of research. In assessing the relevance, the panels are instructed to assess particularly the

- *societal quality* of the submitted work (this aspect refers mainly to active interaction with external stakeholders concerning the research and its results)
- *societal impact* of the submitted work (this aspect refers mainly to how the submitted research influences specific stakeholders or specific societal procedures)
- *valorisation* of the submitted work (this refers to activities aimed at making research results available and suitable for application in products, processes and services).

The SEP approach to the impact of research is quite interesting in its educational tone: only one aspect of societal relevance, the societal impact, focuses on the actual fate of the research achievement in the wider society. The two other aspects, the societal quality and the valorisation, highlight rather the researchers' duty to promote the societal impact of their research. If the N5T universities decide to construct a joint framework for approaching and promoting, or measuring and demonstrating, the societal impact of research at the N5T universities, incorporating the SEP's culture- or practice-moulding elements into the approach could be a strategy worth considering.

Finally, the Dutch approach to measuring and demonstrating research excellence is particularly important for the present purposes, for the Royal Netherlands Academy of Arts and Sciences has complemented the SEP approach by publishing a very interesting and important advisory report concerning the use of evaluation criteria in the engineering and design sciences.[17] This report contains extremely perceptive and helpful discussions and arguments, and the report has influenced greatly and deeply also the present report. The recommendations for quality indicators in engineering are discussed in more detail in Section 3.4 below.

2.6 Finnish Universities of Technology

In 2009, Aalto University carried out a comprehensive, international research assessment exercise (Aalto RAE). The exercise was executed as a peer-review panel assessment by external expert panels. It was a ground-breaking exercise in Finland in two senses.

First, Aalto RAE was the first research assessment in Finland that sought explicitly to assess the social impact of research. Second, the approach developed at the Aalto RAE was later adopted by the Tampere University of Technology and the Lappeenranta University of Technology. Thus, the Aalto RAE approach was practically adopted as the way in which the Finnish universities of technology assessed their research quality in the early 2010s. The joint approach to research evaluation was also seen as the flagship of the recently launched co-operation project of the three universities. This warrants discussing the Aalto RAE approach of the Finnish Universities of Technology in the present context, although the universities do not form an official network or association.

In Aalto RAE, the assessed units were allowed to present whatever evidence they saw fit concerning the social impact of their research activities. They were asked to provide examples, but the manner of presenting the case studies was not instructed rigidly and no case studies were

[17] See *Quality Assessment in the Design and Engineering Disciplines: A systematic Framework* (2nd edition), Royal Netherlands Academy of Arts and Sciences, 2011 (available at https://www.knaw.nl/en/news/publications/quality-assessment-in-the-design-and-engineering-disciplines).

actually graded. Rather, the panels were asked to rate the societal impact of the unit's research effort as a whole on a grading scale from 1 to 5. The highest grade, 5, Outstanding International Level, was defined as follows:

(Note that in Aalto RAE "international" was seen as a quality benchmark referring to the level of interaction expected of academic units in the international scientific community. Thus, even the Outstanding International Level did not necessarily require that the impact was primarily international rather than national in nature, although the panels were welcomed to comment that aspect as well.)

5: Outstanding International Level. Engagement with the society is ubiquitous in the research activities of the Unit. The research at the Unit is highly relevant for the needs of the public and/or private sector making the Unit an exceedingly valued research partner in R&D projects also outside the academia. The members of the Unit are sought-after experts in the public and private sector, and the Unit is a key agent in the development of the society at large. The interaction between the Unit's research and the society is comparable to that of the leading international departments in the field of research of the Unit.

Thus, the Aalto RAE gave very little guidance as to what the societal impact of engineering excellence should look like, and what are the exact criteria for assessing it. This approach was very attentive to the differences and traditions of various disciplines and gave a notable responsibility to the discipline-specific peer-evaluation panels. However, by doing so the Aalto RAE missed the opportunity to let the units of assessment to promote their impact also outside their own discipline. While the motivation behind the Aalto RAE approach is still valid, it seems that the approaches adopted at the UK REF and by the Russell Group are more suitable for demonstrating the impact of research to wider audiences in terms of eye-catching case studies.

However, the actual results of the Aalto RAE confirm rather undeniably that the international evaluators see the ubiquitous industry collaboration as the most important asset and competitive advantage of Aalto University and other Finnish universities of technology. Moreover, the international evaluators clearly understand this asset as a characteristically Nordic feature.

3. Indicators of Engineering Excellence and its Societal Impact

Section 2 above sought (i) to outline the general approaches to measuring and demonstrating engineering excellence and its societal and economic impact that can be extracted from the practices of the selected leading international agents in the field and (ii) to draw rather general conclusions for the N5T from that outline. This Section returns the discussion to the level of indicators and presents the conclusions the Task Force draws from its benchmark of the indicators used by different frameworks and universities.

3.1 General Research Excellence

In the case of general research excellence the international community appears to be converging towards a consensus: research excellence is best measured and demonstrated in terms of high-level publications and, in particular, in terms of advanced, often field-normalised bibliometric citation impact indicators relating to such publications and their publication forums. Indeed, for claims of research excellence to be credible in the eyes of the international community, the excellence should be made visible (also) in terms of such indicators.

To elaborate a little, indicators focusing (or building) on peer-reviewed scientific publications are indispensable because, first, academic freedom requires that the scientific community has the final word concerning the scientific significance and acceptability of research findings, and peer-reviewed publishing is the most important instrument for this peer evaluation. Publishing research results in a peer-reviewed scientific journal is the main method for striving for the kind of collective acceptance (of the scientific community) for one's research results that can be seen as a necessary condition for the research results to count as scientific knowledge. Second, for leading universities of technology it is of utmost importance that the design elements build on state-of-the-art scientific knowledge, and indeed in many cases the design products are developed in tandem with advancements in the relevant sciences. Third, an aspect that distinguishes academic engineering design activities from the design activities of professional engineers is precisely the essential connection to scientific research reported in scientific publications. Moreover, academic engineering design is largely concerned with novel and fundamental design problems, and disseminating the results in academic publications makes the knowledge generated in the design process available to others within and outside academia.

In summary, the bibliometric indicators that are generally used in evaluations of academic excellence are important for measuring and demonstrating also engineering excellence. However, it must be understood that these indicators are developed and work best in the context of basic natural sciences, medicine and life and bio sciences. There are many aspects of engineering excellence that such indicators simply fail to capture. First, some end products of engineering research are design artefacts, not academic journal publications. Second, many engineering projects are not only highly multi- and interdisciplinary in nature, but also intertwine basic scientific research with engineering design. Published reports of such projects are not always very suitable for being published as articles in the journals with highest impact factors and may then find their way into journals with very different citation cultures. It is important to note that the very features that may make the projects unpublishable in the leading scientific journals – high interdisciplinarity, close connection to particular design artefacts – are not as such signs of lower

quality; rather, they are elements essential for excellence in engineering, if not in basic natural sciences.

Measuring excellence exclusively with indicators that fail to acknowledge major aspects of excellence in the field in question poses the danger of steering the direction of future engineering research away from those unappreciated aspects of excellence and, thereby, away from engineering excellence. Even in areas where such development might be desirable, the development must not become reality as an unintended consequence of sloppily planned quality assessment practices. In sum, bibliometric indicators do reveal a certain type of excellence quite reliably, but they remain blind to some other forms of excellence that are constitutive of excellence in engineering disciplines.

3.2 General Education Excellence

Education excellence is a somewhat more elusive phenomenon. Moreover, indicators of the excellent quality and impact of education are quite often conceptually tied to the national higher education policies and frameworks. However, also here the main international approaches are converging towards a shared direction emphasising the graduates' employability and well-structured and managed degree programmes, including the graduation and retention rates of the programmes.

While the N5T universities are strong when it comes to the employability of their graduates (which indeed is perhaps the main route to societal impact for any university), the other aspect, well-managed degree programmes, is an area that warrants different kind of attention. Many new international rankings, such as the U-Multirank, tend to follow the example of Anglo-American, student-centred rankings and league tables and highlight aspects relevant for students looking for a place to study. With the rapid development of the European Higher Education Area, this approach is becoming gradually more important also in Europe and, thereby, in the Nordic countries. Moreover, this approach is increasingly interpreted such that a central indicator of high-quality education is the proportion of students graduating in the normative time period, which according to the Bologna mode that tends to define the European standard is three years for the bachelor degree, two years for a Master's degree and four years for a doctorate.

The Nordic culture of university studies, within which students' study paths are much less strictly controlled, sometimes struggles to be compatible with this approach. This culture is very different from e.g. the Anglo-American culture where the students follow their class rigidly and, consequently, finish their degrees at the same time. The Anglo-American model tends to be rewarded by evaluations of education quality, and the Nordic model punished. Accordingly, if the N5T universities desire their degree programmes to be internationally attractive, the N5T universities should perhaps focus somewhat more on supporting their students to finish their degrees in the normative time period.

Alternatively, the N5T universities could also aim for turning this cultural discrepancy into a strength, for example by communicating to prospective students that while the degrees are expected to be finished in the normative time period, the system is nonetheless also sufficiently flexible for allowing students to construct atypical and personalised study paths that e.g. combine university studies with relevant work experience. If the N5T universities choose this approach, the

N5T universities should also seek to ensure that international rankings recognise this as a strategic choice rather than a quality failure of the degree programmes. Students with personalised study programmes could, for example, be in some cases classified as part time students.

3.3 Societal and Economic Impact

There appears to be wide-spread international agreement that the high-quality of engineering design activities, such as the production of technical artefacts and the design of more optimal processes to meet the needs of users, is an indispensable part of engineering excellence. Engineering design activities feature also as major building blocks of the societal relevance and economic impact of academic engineering excellence. The benchmarking exercise suggests that there are two different but rather widely applied approaches to measuring and demonstrating excellence in societal impact.

A widely adopted approach uses as indicators of excellent societal relevance and economic impact such well-known measures as the number of patents and spin off companies, or the amount of external funding from private sources. These are important indicators and they are indeed commonly used by technical universities, national evaluation systems and associations of universities. However, there appears to be equally unanimous international consensus that these indicators (and their variations) nonetheless fail to do justice to the extraordinary depth of the societal and economic impact of excellent academic engineering. In particular, the customary indicators appear to revolve around very indirect indicators concerning the impact a piece of research or education has on societal well-being and economic growth without really being able to analyse or demonstrate that very impact. This realisation is perhaps the main motivation behind the growing interest in the more qualitative case studies.

At least Finnish and Swedish universities encounter a further problem with the traditional indicators of societal and economic impact: In Finland and Sweden, patents based on university research are not registered as patents of the university, but as belonging to the individuals who carried out the research. Thus, international ranking organisations that use public databases fail routinely to recognise the patenting impact of Finnish and Swedish universities. This, in turn, makes it even more difficult to acknowledge the huge impact engineering research has on renewing and developing existing companies and large scale industries. The technology transfer offices of the N5T universities face a particular challenge in making the role of the university visible in terms of patents based on academic research.

Finally, a related opportunity for measuring and demonstrating the economic impact of engineering excellence is based on the fact that the Nordic societies with their well-developed and open statistical and economic data sources make the economic impact of the N5T universities a particularly suitable object for scientific, e.g. econometric, studies. There are already very promising and important openings to this direction, such as the pioneering work at the Technical University of Denmark,[18] but the N5T universities might wish to consider supporting scientists to adopt a wider, Nordic approach to this cluster of research possibilities and promoting the wider appreciation of the research results.

[18] See http://www.dtu.dk/Om-DTU/strategi_aarsrapporter_mv/analyser.

3.4 The Dutch Quality Assessment Framework for Design and Engineering Disciplines

The discussions above point out the direction where the use of excellence and impact indicators should, in the opinion of the Task Force, proceed. The general thrust is that one should apply internationally acknowledged and appreciated indicators but complement that work with more qualitative documentation. If this documentation is to be graded, there probably is no substitute for using peer-review committees to perform the task. This in in line with the consensus reached during the last decade or so in the quality assessment research: the future of serious quality and impact assessments lies most probably in the balanced combination of advanced numeric indicators and peer-review evaluations.[19]

To conclude the present Section, we wish to discuss one particularly interesting and helpful proposal concerning the indicators to be used in engineering disciplines, presented by the Royal Netherlands Academy of Arts and Sciences. Their approach shares the view of the Task Force concerning the role of design activities in the engineering disciplines as well as the importance of peer-review. In addition to being very well presented and thought-through approach, the Dutch framework is very suitable for the present context also because (i) in global comparison the operational environment of the Dutch universities is relatively similar to the Nordic context and (ii) as argued above, the Dutch approach to academic engineering highlights deep industry collaboration in a manner not so different from the N5T approach.

The Dutch report proposes the following list of criteria to be applied when assessing quality and impact in the engineering disciplines. [20]

	Indicators for Output	Indicators for Person
Scientific Quality	Scientific Publications (Articles, conference papers and books as well as citation analyses) Designed Artefacts (Peer-reviewed artefact + documentation) Research Impact (Documented use of scientific products (methods, instruments, artefacts etc.) by other researchers) Potential Research Impact	Recognition by Scientific Community (Prestigious memberships, awards and grants) Editorships Considered Expert by Peers (Advisory roles, keynote lectures, invitations to assessment and programme committees etc.) Research Impact across the Course of Career (Citation score, contribution to developing a “school of thought”)
Societal	Use of Results by External Stakeholders	Considered Expert by External

[19] Cf. Henk F. Moed: ”The Future of Research Evaluation Rests with an Intelligent Combination of Advanced Metrics and Transparent Peer Review*”, Science and Public Policy* 34(8), 2007, pp. 575-583 or Linda Butler: “Assessing University Research: A Plea for a Balanced Approach”, *Science and Public Policy* 34(8), 2007, pp. 565-574.
[20] See *Quality Assessment in the Design and Engineering Disciplines: A systematic Framework* (2nd edition), Royal Netherlands Academy of Arts and Sciences, 2011, p. 31 (available at https://www.knaw.nl/en/news/publications/quality-assessment-in-the-design-and-engineering-disciplines).

Relevance	(Contributions to solving societal problems, market introductions, income generated by use of results, spin-off companies, patents and artefacts used) Use of Results by Profession (Artefacts, methods, instruments, standards, etc.) Involvement of External Stakeholders in Scientific Output (Potential Societal Relevance) (Businesses or other external organisations involved in guiding research projects, contract financing by potential users, public financing relating to societal questions, valorisation grants) Contribution to Knowledge Dissemination (Professional publications, exhibitions etc.).	Stakeholders (Advisory and consultancy work, positions in industrial r&d) Considered Expert by Profession (Prizes, awards, retrospective exhibitions) Contribution to Knowledge Dissemination (Activities in popularising science, contributions to public debate, training of professionals, industrial placement of doctoral graduates)

From the (abridged) table of recommended indicators it is clear that the context behind the proposal is indeed one where a unit of assessment seeks to demonstrate the quality and impact of its research activities to peer-evaluation committee. The proposals are largely not suitable for being used as mutually commensurable quantitative indicators. Hence, their main value for the present task is to give further illumination concerning the aspects a possible N5T template for documenting case studies should take into account.

Another important lesson is the distinction between more general indicators applicable to research outputs on the one hand and very subject-specific indicators applicable to persons. It seems rather clear that all the person-centred indicators are such that they require a case-by-case approach of a peer-review committee, where the merits of each submission are evaluated by peers who are particularly familiar with the specific field of the person evaluated. Only peers in the same field can in a meaningful way assess e.g. the relative merits of editorships in different journals or being invited to deliver the keynote address in a certain conference. The prestige of different awards is in many cases also something only peers can evaluate. Even career-length citation scores, such as the H index, are simply incommensurable across disciplinary boundaries. We cannot envision a process of turning such person-centred indicators into aggregative indicators meaningful at the level of a multi-disciplinary institution. Thus, their use should perhaps be restricted to qualitative evaluations within a single discipline, such as tenure reviews of individuals or qualitative peer-reviews in research assessment exercises. It seems that there simply is no common currency for creating cross-disciplinary sum indicators on the basis of this kind of subject-specific and subject-relative data.

4. Conclusions and Recommendations

In this report we have argued in support of the following proposals.

(1) Ubiquitous, deep, long-term and influential industry collaboration is a characteristic feature of the N5T universities that forms a competitive asset for the universities even in global context. The N5T universities are thus uniquely capable of acting as central nodes in innovation networks and ecosystems consisting of universities, businesses, public sector agencies and other organisations. This makes the societal and economic impact of the N5T universities rather remarkable.

(2) However, received quality and impact indicators struggle to recognise and acknowledge this aspect of engineering research and education. Thus, the N5T universities have a particular motivation to make this impact and the whole way of working visible. To achieve this, the N5T universities should devise a systematic framework for documenting both their design activities and the societal impact of their activities. In the international community, the preferred method for doing this is to construct a systematic way of collecting particularly eye-catching case studies as examples of excellent and high-impact research and education projects and achievements.

(3) The N5T framework and template of documenting and demonstrating societal impact in terms of case studies could highlight the traditional Nordic values of sustainability, collaboration, internationalisation, innovation and excellence.

(4) The N5T framework for documenting societal impact and design quality in terms of case studies should also be devised such that it strengthens the culture of promoting the impact of academic activities.

(5) If such framework is to be used in actual measurement and evaluation of quality (and not merely in explicating and demonstrating quality and impact), the use of peer-review committees cannot be avoided.

(6) The received quantitative indicators of quality and impact (in particular, bibliometric indicators) must not be overlooked either: they are indispensable for any claims of high quality and impact to be credible. It is just that they cannot cover the whole range and many faces of engineering excellence and must be complemented with qualitative information and peer-review.

(7) The Nordic societies with their well-developed and open statistical and economic data sources would make the economic impact of the N5T universities a particularly suitable object for scientific, e.g. econometric, studies, which would again give extra weight for the claims of high impact. The impact studies concerning the productivity gains associated with R&D collaboration and hiring engineering graduates conducted by the Technical University of Denmark may serve as sources of inspiration here.

(8) The N5T universities should review what possibilities there are for speaking more with one voice to policy makers, industries and the public at large. Indeed, in the Nordic countries the N5T universities could adopt a role somewhat similar to the role the Russell Group universities have in the UK: the N5T universities could publish joint reports on the impact of the N5T universities (building on the systematically documented case studies) that also include policy recommendations. There could also be, for example, an annual N5T conference on the impact of research and education in engineering and a specific

impact award; all these kinds of activities would certainly gain weight from being joint N5T activities.

(9) The N5T universities could consider approaching e.g. the Nordic Council of Ministers to gain support and visibility to the task of explicating and demonstrating the notable excellence and extraordinary impact of Nordic academic engineering.

(10) International rankings tend to treat the difference between the Anglo-American model of rigidly structured degree programmes with a well-defined length, and the Nordic model of personalised study paths with varying lengths, as quality difference rather than a quality-neutral difference between two approaches. The N5T universities need to be clear on their views on this matter and then communicate their position effectively.

(11) A particular problem for measuring the impact of at least Finnish and Swedish universities is formed by the atypical approach to immaterial property rights in the case of academic research in these countries. The technology transfer offices of the N5T universities should ensure that also external evaluations are able to recognise the role of the N5T universities in the patenting activities of their academic staff.

(12) In all quality measurements the fundamental distinction between measuring the quality and impact of outputs and the quality and impact of individuals should be kept clear and intact. Indicators relating to the academic quality and impact of individuals are a sensitive issue and require careful, case-specific treatment by peers who are intimately familiar with the academic field of the individual of question. The N5T universities should consider refraining from constructing university-level, quantitative indicators out of data relating to the academic quality and impact of individuals. At the minimum such indicator constructions should be applied with utmost care and consideration. Achievements and success stories of individuals are, however, quite suitable for energising case studies as well as for communication purposes.