The problem of scientific theory: the case for introducing science studies for first-year students – A Discussion Paper

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Abstract

The course Communication in Engineering Sciences, where I have been teaching, is mandatory for all first-year students at the Computer Science and Engineering programme. There we teach scientific writing, and the students are required to base their papers on a scientific theory. This is a tough requirement for students new to higher education! And is it a relevant one?

A quick survey of different report-writing instructions from various academic sources confirms this ambivalence to including a theory section or not.

The motivation for including theory already at this level is that they will be asked to include such a section in their final degree examination report, so they better start learning what that means. But can you ask them to write scientifically without them first having been educated in science?

A second question is if science and scientific theories are relevant knowledge for students where few wish to continue to the doctorate level: the majority plans to get jobs outside the academy. Swedish legislation (Högskolelagen, 1977:218) states that all education at universities and colleges must be based in science. But what does that mean?

When looking at these questions, I also believe we have to approach the perceived difference between science as “pure” and technology as “applied”. In short: how scientific should a technical education be?

I argue that the solution could be to see – and teach – science and ‘the scientific method’ as something that would benefit our students also in the non-academic workplace after a finished degree. The key, I believe, is motivating them by teaching “scientific reasoning” (i.e. science rhetoric) early, and, most importantly, convince our students that this can apply to problem-solving in general.

In this day of “truthiness” and unfounded “facts” that go viral on the internet, perhaps it is motivated to introduce the scientific method on a broader scale at KTH.
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1. Introduction
This is a discussion paper, where I hope to raise interest for introducing basic science studies and science rhetoric for first-year students at KTH, The Royal Institute of Technology. I think there are several benefits to this: a deeper understanding of how to pursue scientific inquiry, which will assist students when writing their examination theses, but also, I believe, improve their problem-solving skills even outside the academy.

1.1 Background
I have been teaching the course “Communication in Engineering Sciences” for two semesters, autumn of 2013 and 2014: a total of 5 groups, or more than 140 students. When asking these first-year students on the Computer Science and Engineering programme, only a handful respond that they are interested in pursuing an academic career – the majority wants to get jobs as programmers (programming computer games seem to be the most popular career choice).

And yet, there I am, requesting they learn how a scientific paper should be structured, what is meant with scientific theory and method, and how to argue scientifically. The students complain, as can be seen in the course evaluations, and their main complaint is that they don’t see the point of learning these things. And by extension, I conclude that they see their examination theses mainly as a necessary chore in order to obtain their degree.

This I would like to change.

1.2 Theory or no Theory, that is the Question
In the autumn of 2014, another problem appeared, when focus increased on including a theoretical background in the students’ writing assignment. Most of my students, being completely new to higher education, struggled hard with this: with their limited pre-understanding of theoretical concepts, why they are necessary, how they are used, and what they comprise of. This is what prompted me to write this discussion paper.

In class, I have tried to compensate for the limited training in scientific theory provided in the course lectures, but I have found reasons to question the necessity of including theory in the first place. I have reached this conclusion from a practical as well as from a theoretical perspective. The practical view is based on a survey of literature on writing academic papers, where a section on theory quite often is not included, and in the theoretical view from a discussion on the perceived difference between “science” and “technology”.

1.3 The Alternatives?
I trust the reader has spotted the logical fallacy presented above: my contention that we need to train our new students better in scientific theory before asking them to write reports and papers collides with the idea that we do not necessarily need to include a theory section in the first place.

Perhaps there are alternatives to the current organization of the writing courses:
a) focusing on scientific argumentation, whether including theory or not
b) motivating our students to learn scientific argumentation by demonstrating how it can be used outside the academy, in problem solving in the workplace, for instance.
c) Introducing science studies (and the role of theory) before teaching scientific writing.

2. In practice: how other institutions teach scientific writing
I have done a quick survey of different report-writing instructions from various academic sources, and I found that they do not consistently include a theory. I do not claim the investigation to be complete or thorough, it is a sampling based on easy access. I have focused on technical reports, and the results are inconclusive: some include theory, some do not. This, I believe, confirms the need for a further discussion.

The web resources were found by using the phrase structure of a technical report without citation marks to enable variations in the ordering of these words, and results had to be from official university web sites in order to be included.

2.1 Example 1: Our current course book
For the autumn term of 2014, we changed the course book to How to Write Dissertations & Project Reports (Smarter Study Skills series) by Weyers & McMillan (Swedish title: Studera smart: Så lyckas du med uppsatser och rapporter, Pearson Education, 2010). The book provides lists of what different types of reports should include, but none of these include a theory section.

The course book lists the following structure for a scientific report (my translation with numbers added – see Appendix 1 for a copy of the original).

1. Title/Cover sheet
2. Abstract
3. Foreword
4. Table of contents
5. Introduction
6. Material and method(s)
7. Results
8. Discussion/Conclusions (with a summary)
9. Abbreviations and glossary
10. (Index)
11. Bibliography and additional literature
12. Appendices

In the course, we asked students to add a theory section between item 5 and 6 in this list.

See Appendix 1 for a copy of the complete list from the course book (in Swedish).
2.2 Example 2: The previous course book

In 2013, the course book was Rienecker & Stray Jørgensen’s *Att skriva en bra uppsats* (2006). The authors write that the classical scientific disposition should be as follows (p. 166, my translation, and numbering):

1. Abstract  
2. Table of Contents  
3. Introduction  
4. Theory, method, “state of the art”  
5. Investigation  
6. Results  
7. Discussion  
8. Summary  
9. Conclusions  
10. Recommendations  
11. Bibliography  
12. Appendices

The book describes theory as system of tenets (or assumptions) in a subject area that can be used to *describe, explain and predict* the subject’s phenomena, and which forms the framework of understanding of the subject (p. 279, my emphasis). This is what our students mostly struggled with, as most of them lacked knowledge of theories suitable for their field of study.

In this course book, theory is thus included, but we received many complaints on the book. It is quite long (416 pages), and was considered irrelevant by many, as for instance the examples are from social sciences, pedagogy, and literature studies: there are no specific descriptions relating to technical reports in this book. The new course book mentioned above seems better suited for technical reports as it includes sections on research methods, and working with numbers and data etc. It is also more concise (301 pages in smaller format).

2.3 Example 3: Instructions from the University of Edinburgh

Easson & Bruce at The University of Edinburgh School of Mechanical Engineering has published instructions on how to structure a technical report. They write that a report on an *experimental* project would include theory, experiment, results and discussion (p. 3), and follow with a recommendation: “Make clear the relationship between the theory and the experimental objectives” (p.9), and include the following guide for the report layout (p.7, my numbering):

1. Title  
2. Summary  
3. Introduction  
4. Theory  
5. Experiment  
6. Discussion  
7. Conclusions
8. Appendix 1 – References
9. Appendix 2

Comment: In the course Communication in Engineering Sciences, due to the limited time available, we recommend our students to make a literature study, but a few choose to conduct their own experiments nevertheless. If using this example for report writing, we must assume that the students are first taught theoretical models before setting up their experiments.

2.4 Example 4: Instructions from Monash University
Monash University, in Melbourne, Australia, is according to their own website a top-ranking university, and has published an ambitious guide to various types of academic reports under the heading Language and Learning Online. In the instructions for writing technical reports, a theory section is not included. They write that a report usually has these components (my numbering):

1. Title page
2. Summary
3. Table of Contents
4. Introduction
5. Middle sections with numbered headings (i.e., the body of the report)
6. Conclusions
7. References
8. Appendices

Each item in this list links to a new page that expounds the subject further. The middle section mentioned above refers only vaguely to theory: “presents the information from your research, both real world and theoretical, or your design”.

2.5 Example 5: Recommendations from KTH
On KTH Social’s website, there is a pdf document written by Bengt Molin in 2011 that outlines what we must assume are the KTH’s official recommendations on report structure (my translation):

1. Cover page
2. Abstract
3. Foreword
4. Table of Contents
5. Introduction
6. Main section (analysis, execution, or description)
7. Results, conclusions, and recommendations
8. Bibliography
9. Appendices

In this list, no separate theory section is included, but further on in the document, it says the introduction should include a theoretical or historical background (p.1, my emphasis). He continues to say that the main part of the report consists of an account of your work and how
you arrive at your results. The disposition can vary, depending on subject and purpose, and *may* for example include a theoretical background.


A section on theory seems to be optional in this description, but the short format is probably the reason for not including further information on how “theoretical background” is defined in this context.

### 2.6 Conclusions from survey

From the above examples, it would seem that a theoretical section is not always considered mandatory. Note that the descriptions above are not all consistent: some claim to be general, and valid for all types of scientific writing, while others are particular to technical reports.

It is precisely this lack of consistency that motivates, in my opinion, that KTH further discuss how we can introduce report writing – with or without a theoretical section, and provide our students with a more consistent support in this matter.

### 3. Science and scientific theory – the relationships

A second question to ask relates to the greater issue if science and scientific theories are relevant knowledge for students where few wish to continue to the doctorate level: the majority in my classes plan, as mentioned, to get jobs outside the academy.

Swedish legislation (Högskolelagen, 1977:218) states that all education at universities and colleges must be based in science. But what does that mean, when “science” can mean several things? It might thus be beneficial to discuss the terminology concerning science, and try to untangle the different approaches to a scientific endeavour.

#### 3.1 Is your science the same as mine?

One reason why my study of teaching practices above shows such diversity may be that the underlying assumptions vary as well. Here I refer to “science” in the broad, more philosophical, sense, not the various types of sciences, like medicine, physics, social sciences, and so on. Here is, I believe, a connection to the discussion on the perceived difference between “science” and “technology”.

The background is that in my teaching I have made a distinction between “basic” and “applied” science. In this I have further considered “technology” to be “applied” science. But when I started to look for definitions to use in this discussion paper, I realized what a tangled knot I had gotten myself into: these categories have been discussed and debated for a long time. Thus I will try to summarize below some of the things I have learned when investigating this debate, in the hope that it may clarify the current situation.¹

¹ Too late to be included in this paper, I learned of Per Norströms dissertation “Technological knowledge and technology education” from 2014, available here: [http://www.avhandlingar.se/avhandling/7f036d3636/](http://www.avhandlingar.se/avhandling/7f036d3636/)
3.2 Science? What science?
At the most abstract level, the Encyclopædia Britannica Online defines *science* as “In general, a science involves a pursuit of knowledge covering general truths or the operations of fundamental laws” (my emphasis). This description is almost identical to the description of what a scientific *theory* is, as described by Rienecker & Stray Jørgensen quoted above: this “system of tenets … which forms the framework of understanding of the subject” (p. 279) sounds very much like the “general truths” and “fundamental laws” that constitute science. And the Encyclopædia Britannica Online defines *scientific theory* as the “A scientific theory is a structure suggested by [empirical] laws and is devised to explain them in a scientifically rational manner”.

Perhaps we should describe science as the pursuit to generate scientific theories? If so, we would be obliged to include a scientific theory if we are to call our investigation “scientific”.

3.3 Pure/basic science
Note that another expression exists, “pure science”. However, let us not even go there – as Gruender commented already in 1971, this should be considered a misnomer, to be abandoned (p. 463), as it may lead our thoughts to “noble” motives and/or impossible and “other-worldly” pursuits (p. 459). We should use the term basic or fundamental science instead (grundforskning in Swedish), which, according to Gruender, “can be identified by its search for laws and natural constants of the broadest possible scope” (p. 463), and “by the pleasures of just finding more knowledge” (p. 457).

Anyway, whether “pure” or “basic”, these descriptions match the generic definition of “science” as quoted above.

3.4 Applied science/technology
Returning to the Encyclopædia Britannica Online, they define *technology* as “the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment”.

Gruender accordingly describes applied science and technology as attempting to “apply knowledge for the solution of human problems” (p. 463). My simplistic classroom teaching of separating basic and applied/technological science can, I’m relieved to say, be somewhat pardoned: as Sismondo (2010) writes, technology is “typically seen as simply the application of science” (p. 1), and this view is centuries old (p. 93). He continues:

Technology has tended to occupy a secondary role, for a simple reason: it is often thought, in both popular and academic accounts, that technology is the relatively straightforward application of science. We can imagine a linear model of innovation, from basic science through applied science to development and production. … Technology combines the scientific method with a practically minded creativity. (p. 8).

Sismondo further believes that this view tends toward a form of technological determinism (p. 9), but neither science or technology is a “natural” kind, they don’t have any simple properties that define it once and for all (p. 11).
3.5 Creating/building knowledge
Kline says that technology is directed toward human use, and not solely toward increasing understanding (Kline according to Karns Alexander, 2012, p. 520). I emphasize “solely” to point out the openness of the categories: applied science and technology also aims to increase knowledge – but not knowledge of the fundamental laws, then. These descriptions places “pure” or “basic” science as abstract ideas, where applied science, which I as you have noticed equate with technology, can be seen as the embodiment of these ideas in the physical world.

This description creates a model where you first have to have an idea (i.e. a scientific theory) in place, and then you start to ponder how to embody this idea in the world. This is what is meant with “the linear model”.

3.6 The linear model, “Project Hindsight” and the steam engine
The linear model, were “basic” science turn into “applied” science or technology, or if you like, and an abstract idea becomes a concrete practical tool, became a rhetorical tool used by scientists, management experts, and economists, developed over the first two-thirds of the twentieth century. This model has been thoroughly critiqued, for instance by Project Hindsight were the US Department of Defence conducted an audit to discover how useful basic science was, after having invested heavily in basic research. Tracing back from the development of 20 weapons systems, they classified 91% of the key events as technological, 8.7% as applied science, and 0.3% as basic science (Sismondo 2010: p. 93).

The steam engine is also a popular example when critiquing the linear model: according to Sismondo, it is widely accepted by historians of technology that “science owes more to the steam engine than the steam engine owes to science” (p. 94), meaning that we had functioning steam engines before we had a scientific theory that described the natural laws that made them work: the technological invention stimulation scientific research, not the other way around (Karns Alexander 2012: p. 523). The theory of “phlogiston” is just an amusing story today!

Technology may thus be “relatively” divorced from science, according to Sismondo, and there are arguments that technological practice is autonomous from science. However, he continues, some argue that the categories science and technology are not sufficiently well defined and distinct (p. 94-95). That may be a classical problem: that we strive to define what are in fact actions, or “verbs”, as if they are things, or “nouns”; that we seek essences instead of processes.

3.7 Actions over essence – focus on the scientific method instead?
Instead of asking “what is science” and “what is technology” respectively, what if we focus instead of what people to when they claim to “do” science or technology? Then we move away from the discussion of theory as “scientific laws”, linearity and so on, and consider instead on the scientific method. “Method” is defined as “planned approach for achieving specific results” (NE), and “scientific method” is described in the Encyclopaedia Britannica Online as “techniques used in the construction and testing of scientific hypotheses”. These
general descriptions are admittedly vague, but they do emphasize that they relate to actions, to something we do for a specific purpose.

Each “science” has established their own methods: you do different things when you are a chemist, or a physicist, or a social scientist, or a linguist, and so on.²

3.8 Science as a rhetorical practice
As a rhetor, I will probably surprise no-one by claiming that one way to view science is as a rhetorical practice, where the form of the arguments varies with the type of science – or technology – within which we claim to work. We can see both scientific and technological work as a theory of narrative: of a struggle to establish the more plausible story, that must at minimum link agreed-upon facts and be supported by credible arguments. Closure is achieved only when, and if, one story achieves consensus (Myers according to Gross 1990: p. xxvi).
This view depends on persuasion: “only through persuasion are importance and meaning established” (Gross 1990: p. 4). Gross writes:

The rhetorical view of science does not deny ‘the brute facts of nature’ … Whatever they are, the ‘brute facts’ themselves mean nothing; only statements have meaning, and of the truth of statements we must be persuaded. (p. 4)

I argue that the presence of a scientific theory is not always necessary in order to carry a scientific argument. Instead of squeezing “theory” in at any cost, we might do better if we consider the genre, or the context, within which we are arguing. Is it for this particular purpose relevant to use theory? Then use it. Otherwise, look for other types of argument.

What makes a study scientific lies, therefore, in in the application of an agreed upon set of methods for investigation, and ways of describing the findings and arguing about them, i.e. in the rhetoric specific to each genre.

In my “practical” study above, we could have a flexible approach and motivate the use of a theory section based on the type of problem being investigated, and the genre within which it is positioned, as already mentioned.

4. Conclusion 1: Introducing science studies and scientific reasoning early
What I suggest is thus a more flexible approach to teaching scientific writing, but not in the sense that theory is “out” and another model put in its place. Rather, I would recommend we investigate the rhetorical models for each subject taught here at KTH and keep a flexible approach. There are different ways to argue within a knowledge tradition, say of computer science or in geology. But even in computer science, there are times that a theory might be useful in the investigation, as perhaps the use of psychological theories when resolving an issue in HCI, Human-Computer interaction.

A certain amount of familiarity with the context where the studies are performed may thus be required. Yet I have also found it useful to introduce science theory to the first year students.

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² Here a language problem presents itself, as “science” in the English language usually refers to the natural sciences, while “vetenskap” in Swedish is a broader category that can include the humanities.
It is a bit of the egg-and-hen-problem: you have to start somewhere. Whether we introduce the scientific reasoning as science studies or as scientific writing, do not necessarily matter, I believe, but somewhere along the students’ progress through their programmes, the two should be combined. And here theory could be introduced at the level suitable to the students: and ideally, be well motivated before the task of writing commences.³

Finally, if we focus on the scientific method and the genre-specific rhetoric, we don’t have to address the thorny problem of defining whether we are conducting basic or applied science, or technology, et cetera.

What we want to produce is knowledge that holds up to scrutiny according to scientific ideals.

5. Conclusion 2: Rhetorical skills as a motivating factor

Whatever field of study, the scientific method have some common features: the corroboration of facts, the coherent argument that fits the chosen field, and opposition: the peer review. The purposes of these actions are all to strengthen the argument and remove doubt were possible. These are actually goals that would suit any pursuit of knowledge, an ideal worthy of being encouraged also outside the academy.

In these times of “truthiness”, this might be an ideal worth striving for! “Truthiness” was Merriam-Webster's #1 Word of the Year for 2006, introduced by the TV-satirist Stephen Colbert, as meaning “truth that comes from the gut, not books”. The American Dialect Society described it as “the quality of preferring concepts or facts one wishes to be true, rather than concepts or facts known to be true” (Merriam-Webster).

Today we also talk of the “factoid”: “an invented fact believed to be true because it appears in print” or “a briefly stated and usually trivial fact”. And surely, any business would do better with better quality research and development.

So even if our students do not wish to pursue an academic career, learning the scientific method and reasoning can be useful for them in their future careers.

If we find the arguments (the rhetoric) to convince them that it is a worthwhile endeavour. Surely we have the confidence in our own methods to convey this to our students?

6. Suggested topics for discussion

I cannot claim to have many answers on how best to teach science and scientific reasoning, but I hope for a broad discussion on the subject at this institution. For the workshop, I have included some suggested topics for discussion, in no way claiming this list to be exhaustive:

1. What benefits can be gained in teaching by distinguishing science into the categories of basic/pure science, applied science, technology, and so on?
2. If beneficial, how can these categories best be defined for the purpose of effective teaching?

³ Is CDIO the answer? Unfortunately, I am unfamiliar with this approach, perhaps there will be a chance to discuss it at the workshop?
3. While acknowledging that the categories are not particularly clear-cut, can certain subjects (or schools at KTH) be said to focus more on one of these categories over the others?

4. Can it be productive for the students’ understanding of scientific inquiry to investigate what type of research questions are typical for the different subjects taught at KTH?

5. Is it correct to assume that a section on “theory” is not always necessary in order to conduct a scientific investigation at student level?

6. What are the benefits of learning “scientific theory”? How can we motivate students to embrace this? How and how soon can it be introduced to our students?

7. What is the best order for introducing science studies, scientific theory and method, and scientific report-writing?

8. Can scientific reasoning be linked with good decision-making in non-scientific settings? What would the arguments look like? Can this be verified in some way?

7. Afterword

I mentioned at the start that most of my students are intent on working outside the academy, and that many complain over the course. This is fortunately not true for all of them, so I would like to finish on a positive note with this statement from one of the students in the Communication in Engineering Sciences course:

    I think [the course] is extremely valuable, but most of the computer studies students seem only to want to programme, and are stressed over the InDa5 course. They don’t understand what a great difference a course like this may have on the rest of their studies and their careers, but I know from before how important it is.

    *(anonymous student from my B-group in the on-line course evaluation, autumn 2014)*

These words confirmed to me that it is worth discussing improving the communication skills of our students with other teachers here at KTH.

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4 Jabe Bloom, American entrepreneur and PhD-student at Carnegie Mellon, is one example of someone trying to bring scientific reasoning into the business world, see for instance his lecture “Learn like a Scientist” [https://vimeo.com/80132202](https://vimeo.com/80132202)

5 Introduktion till Datalogi, Swedish name of the introductory course in computer science.
Bibliography:


Monash University (undated) *Our rankings.* Available at: http://www.monash.edu/study/rankings/rankings [2015-02-11].


**Appendix 1:**

Table of report structures from McMillan & Weyers (see section 2.1 above):

<table>
<thead>
<tr>
<th>a) Uppsats</th>
<th>b) Vetenskaplig rapport</th>
<th>c) Labbrapport (naturvetenskaplig)</th>
<th>d) Mindre formell rapport eller litteraturgranskning</th>
<th>e) Ekonomisk rapport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titelsida/ försättsblad</td>
<td>Titelsida/ försättsblad</td>
<td>Titelsida/ försättsblad</td>
<td>Titelsida/ försättsblad</td>
<td>Titelsida/ försättsblad</td>
</tr>
<tr>
<td>Abstract (sammhandrag)</td>
<td>Abstract (sammhandrag)</td>
<td>Inledning</td>
<td>Inledning</td>
<td>Exekyiv sammanfattning</td>
</tr>
<tr>
<td>Förord</td>
<td>Förord</td>
<td>Material och metod(er)</td>
<td>Huvuddel av texten</td>
<td>Förord</td>
</tr>
<tr>
<td>Innehållsförteckning</td>
<td>Innehållsförteckning</td>
<td>Diskussion/ Slutsatser</td>
<td>Avslutning</td>
<td>Innehållsförteckning</td>
</tr>
<tr>
<td>Inledning (m. bakgrund)</td>
<td>Inledning</td>
<td>Källförteckning</td>
<td>Källförteckning</td>
<td>Huvuddel av texten</td>
</tr>
<tr>
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<td>Material och metod(er)</td>
<td></td>
<td>Källförteckning</td>
<td></td>
</tr>
<tr>
<td>Resultat</td>
<td>Resultat</td>
<td></td>
<td></td>
<td>Bilagor</td>
</tr>
<tr>
<td>Diskussion/ Slutsatser (med sammanfattning)</td>
<td>Diskussion/ Slutsatser (med sammanfattning)</td>
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<td></td>
<td>Ordlista</td>
</tr>
<tr>
<td>Sammanfattning/Summary</td>
<td>Förkortningar och ordförklaringar</td>
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<td>(Sakregister)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilagor</td>
<td>Källförteckning och kompletterande litteratur</td>
<td></td>
<td>Bilagor</td>
<td></td>
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</tbody>
</table>