Trusting results – An exploration of physicists' appraisal of their own and others' research

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Abstract

The research aspect of being a scholar in physics does not only include producing solid research results, ready for archiving in the physics literature, but involves a rich interplay with peers, colleagues, and the research community. This article focuses on a prominent part of that interplay, namely on how researchers in condensed matter physics appraise the trustworthiness of their and others' research results. Through an analysis of the ways physicists speak of trust in interviews, informed by phenomenography, four different aspects of the complex phenomenon of appraising trustworthiness are brought out, in which dimensions of variation are identified and explored. The four different aspects are encapsulated in four questions to be put to the data: 1) What is it that is spoken of as being appraised when discussing trust? 2) What is the context in which the object under consideration is appraised? 3) How is appraising trust anchored in trustworthy elements and what is their nature? 4) What is spoken of as characterizing the quality of the process of establishing trust? The variation in these four aspects together portrays the educational dimension of what it means to appraise physics research. These results further the understanding of the ground for the collaboration, peer review and communication in the research community, and portray part of what it means to be a scholar in the research capacity.

Introduction

Research is a complex activity, whether it is concerned with human activities, such as learning, or the world around us, such as physical phenomena. There are aspects of the research process that are not focal for the researcher, and insights into these can contribute to strengthening the research enterprise. There are examples of qualitative empirical studies giving some insights into these issues, e.g. exploring how researchers in general conceptualize research (Brew, 2001), exploring material scientists' ways of understanding their research object (Baillie et al., 2001), and exploring how IT researchers understand what their research is about (Pham et al., 2002).

The quality of research is an issue which is of continuous concern for the research community. Traditionally, quality is seen to be guaranteed by the peer review process: prior to publication of studies, results are reviewed by established researchers who comment upon their quality, whether or not they are trustworthy and relevant in relation to the field. To publish a study, in addition to producing the actual research results reported, the researcher therefore has to make judgments about its quality and trustworthiness and judgments about related research and its credibility and relevance. Then other researchers in the field, the referee(s) and the research community, make further judgments.

The question being addressed here, different from earlier empirical studies, is: What is the basis on which all these judgments are made? That answer has to be different in different fields, and the focus of this article is on how researchers in condensed matter physics make, or conceptualize the making, of these kinds of judgments. In this field of condensed matter physics, a straight-forward answer might be that the researchers make use of the body of knowledge to make objective judgments. But on consideration of the epistemological and ontological assumptions demanded of educational research, this is seen not to be the whole case, as is indeed confirmed by this study.

This article reports on an empirical study to explore the qualitative variation in how researchers in condensed matter physics conceptualize issues around trustworthiness in theory and in practice, of their own work and of that of others. It is part of a study which was carried out with a predominantly phenomenographic approach (Marton, 1981; Marton & Booth, 1997; Ingerman, 2002). The phenomenographic approach is focused on exploring the ways in which a phenomenon can be experienced, since

> *"in order to make sense of how people handle problems, situations, the world, we have to understand the way in which they experience the problems, the situations, the world, that they are handling or in relation to which they are acting. Accordingly, a capability for acting in a certain way reflects a capability [for] experiencing something in a certain way. The latter does not cause the former, but they are logically intertwined. You cannot act other than in relation to the world as you experience it."* (Marton & Booth, 1997)

This implies that, in the whole study of which a part is reported here, the research focus was on exploring the variation in the ways the phenomenon "physics research" is experienced by physics researchers at various levels of experience.

The thrust of this article is educational, related to the overall research question, What does it take to become a research physicist (Ingerman, 2002)?. We are thus concerned with physics research education, and how supervisors and departments can support students in achieving sophisticated approaches to appraising their own research and the research they come into contact with. This can be contrasted with other research on research, which is often more concerned with students' and supervisors' conceptions of research (Brew, 2001), students' attitudes to research methods (Murtonen, 2005), and what is understood to be science and good research, across disciplines (Kiley & Mullins, 2005). There is little on the supervision process or input to it. Here we are producing an analytical overview of the ways on which trust in physics research results is considered, appraised and established in order to inform supervision practice.

Method

Data was collected through interviews with researchers at the Physics department at Chalmers University of Technology and Göteborg University, Sweden. Interviews were held with 10 physics researchers in the subfield mesoscopic physics of condensed matter physics. They came from both theoretical and experimental branches of the field (respectively 5 from each) and had different positions which can be grouped as pre-doctoral (6), post-doctoral (2) and professors (2)[1]. The aim was to include a variation across the research topics in focus among the interviewees. The interview was designed to be semi-structured around a number of predetermined themes and open to exploring these themes in ways that might emerge in the particular interview. The interviews were held in English, being the dominant language of discussion of physics in this branch.

After some general questions about physics and their experiences of being involved in physics, the researchers were asked to describe one of their current research topics in detail, which naturally varied within the group. Of particular interest in this article is that they were, directly afterwards, asked "Do you trust your research results?". Later

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[1] Doctoral students have between 1 and 5 years of research experience, Post-doctoral researchers include both post-docs who have a position immediately after graduating and research fellows who are more experienced; Professors include both associate, assistant and full professor equivalents.

they were engaged in a discussion on what it took to trust others' results. The analysis of the phenomenon "trustworthiness" is discussed in this article, in particular how researchers appraise their own and others' research results

The interviews varied in total length between 45 and 120 minutes, mainly depending on the length of time we discussed their research, and covered a number of themes other than trust. They were recorded on audio tape and on video tape, so that the jottings, the sketches and some of the movements of the interviewees were captured.

In line with the phenomenographic approach, the interviews were seen as forming a "pool of meaning" which the variation in ways of experiencing the phenomena of interest are to be seen. However, as it was discussed and described by the interviewees the phenomenon of appraising trustworthiness comprised a number of different aspects and was found to be too complex to be described with a single outcome space, in a way that was meaningful for supervision practice. Further, it was not clear that the data was addressing one and the same phenomenon, since the individual researchers were speaking of research in a broad and general way, related mostly to their own experiences which were not necessarily shared experiences.

Thus we have tackled the data analysis in three stages, which we will share with the reader in the results section: in the first stage there was a consideration of the complexity of the phenomenon which was more obvious in certain interviews than others. From there we identified three broad categories, which were felt to be too general to be of educational value or scientific interest. But that led in turn to a second stage, comprising a thematic analysis which revealed four themes in the data, or aspects of appraising trustworthiness. Now we had four phenomena – aspects of the original research focus – which lent themselves to a genuine phenomenographic analysis since they were identifiably common across the group of researchers who had been interviewed.

Thus we have made an analytical separation of some aspects of trustworthiness, as gleaned from the data, and analyzed them separately for the variation they show in essential meaning. By reading the interviews repeatedly, now as expressions of individual researchers, now as series of extracts related to specific aspects, ways of understanding them evolved. The aim was to discern meaningful variation, or in other words qualitatively different ways in which the researchers experienced what it meant that research was trustworthy.

During a phenomenographic analysis, the researcher strives to take a second order perspective on the phenomenon (physics research) to enable a description of the ways in which the phenomenon is experienced. Such a description constitutes an outcome space, organized as a set of descriptive categories or as a number of dimensions of meaningful variation. Focus is not on the way in which the (pedagogical) researcher experiences the phenomenon, but on the ways the research participants (here the physics researchers) do; in contrast, it is the (pedagogical) researcher who experiences a variation in how the phenomenon is experienced, and seeks meaning and structure in this variation.

These ways of understanding are expressed as dimensions of variation, and they will be described in the third stage of the results section. Example extracts from interviews are presented to support and give substance to this analysis. It was not the aim of the

analysis to produce general and incontrovertible results, but rather results that are both valid and interesting in the local setting, lending meaning to the specific situation being examined, as well as a contribution to the more general understanding of pedagogical issues related to teaching and researching physics at the university.

No personal identifications of the interviewed researchers are given, in order not to advertise their identity. Most of them were men and so the male pronouns are being used to avoid identifying the women, without implying any disrespect to the women physicists who participated. However, those from the same local community might be able to identify individuals by reference to their stated research area. In order to deal with this, a draft of this paper was distributed to give an indication of the data being used and the arguments being presented, and they were invited to comment and criticize over lunch. None came, which was taken as a sign of acceptance.

Results

Stage 1. The complexity of trustworthiness

The phenomenon of appraising trustworthiness was seen from the data to be comprised of a number of different aspects, including what was trusted and how that trust was established. The aspects are clearly not independently constituted, but are intertwined in complex ways which differs from statement to statement. The present analysis does not consider the relation between how different aspects are treated in a single context by a single interviewee; instead they describe the variation within the aspects which are separated analytically.

Before embarking on the descriptions of these four aspects, it is illustrative to look at the following interview extract, where more or less all aspects are taken up as a complex but coherent and interrelated story. It also serves as an example of the type of interpretations and the contextualizations considered during the analysis. When put next to other extracts, the variation can be discerned, while standing alone like this the complexity is seen:

I^2 *Obviously you trust your results, because you have a clear picture of what you are doing. But in the research process: When do you trust your results?*

P_{14} *That's a good question. It's a, you really need to verify over and over again in experiment that you get the same result and you also have to look for possible errors or some impossible parasitic effect that you might not think of.*

There, when asked if he trusts his data, P_{14} immediately refers to the need for repeating the experiment, and for making sure that you cannot think of any other effects that may give similar results. This is how he sees trust in his own research results to be established. What is trusted is, then, the actual measured results, on the one hand, and that they signify or are relevant for some particular and correctly identified effect or physical phenomena, on the other hand. The extract continues:

But in the end when you take some data and you, I think really it's important you that have some degree of analysis and theory of your results so that you can, I can see some people are taking measurements and publishing the measurements and not saying very much about the interpretation of the

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2   In the interview extracts, the interviewer is denoted with I while the interviewees are denoted with P_n for physicist n.

> *measurements and I try not to do that.*

This widens the scope to taking the results from the experimental situation, implicitly to the community of physicists (which is explicitly referred to later in the extract). Now 'some degree of analysis' comes into focus, which is described as figural in what is trusted. It also seems important for how the measured results are to be established as trustworthy within the community. There is also a shift from appraising the trustworthiness of one's own results to applying the same kind of criteria to others' results, implying the community as a context for establishing trust. That is then developed and the different interactions that move the research further are described:

> *In some cases I have to do that because I have no explanation but then I don't, then it's a conference paper and I sort of publish that to make it known to the rest of the community that this measurement has been done and maybe some theoretician is interested and they might find a solution to it, but I think to make a really good paper I think one should really explain why the measurement data looks the way it does, why it depends the way it does under certain parameters and if you do have a coherent picture of the data, if it's, so I would say for reproducibility is of course the key factor, it should be made at least the same measurement on the same sample several times and of course you would like to have several samples that show the same phenomena.*

So, shifting from the community, how trust is established is discussed. That process is loosely embodied in writing 'a really good paper', an ideal, which if applicable lends trust to the results in the paper.

Returning to the interviews as a whole, the notion of appraising trustworthiness was discussed in complex ways. The discussion on whether a piece of research, an idea or a result was trustworthy shifted to focus on different aspects in different parts. As such, the nature of trust was difficult to catch and the analysis puts emphasis on the structural elements, in order to sketch a full picture.

We saw three broad and qualitatively different ways of speaking about trust in research results, which differed in several respects and became successively more complex. The first of these deals with only singular issues, one at a time, which were seen as being either trustworthy or not in an absolute sense. The status of a result is established as true or false, relying on a particular judgment, according to external norms. Different aspects are usually discussed separately or focus is solely on one aspect.

The second category appraises trust by considering multiple perspectives, finding indicators rather than answers. Trust may thus be partial, judged in the context of other pieces of work, in part depending on other researchers' assessment, in part depending on understanding, in part on form. The work considered is not only a specific number of results weighed on their own, but part of a system of results and models, having its own assumptions that have to be explicated and considered.

In the third category appraising trust is a more integrated process, where establishing trustworthiness is a gradual and on-going process. Research is seen as having a historical dimension of importance. Different aspects of trust are considered together, in relation to each other, separately in depth, all in all portraying trusting any piece of research as a multi-faceted issue, as an interrelated whole. It also includes a dimension of acting within a community in order to influence the processes of establishing trust.

Stage 2. Appraising trustworthiness – a thematic analysis

This preliminary analysis is inadequate for our purposes, in that it fails to provide substantial insights into ways of developing an approach to appraising trust, which we want for our research supervisors. However, we see that each category can be restructured in terms of response to four questions to the data, and our analysis continues now in that direction. There are four aspects which we as researchers have constituted, but we are not claiming that they are independent features of the interviewees' experience of trustworthiness. Rather, they are seen as being essential aspects of the research process of importance to becoming a research physicist.

The four questions we identified are in two pairs, one concerning the what and the other concerning the how of appraising trust.

⟨ What is trusted?
  o What is it that is spoken of as being appraised when discussing trust? What delimits the figural object?
  o What is the context in which the object under consideration is appraised?
⟨ How is trust established?
  o How is appraising trust anchored in trustworthy elements and what is their nature?
  o What is spoken of as characterizing the quality of the process of establishing trust?

As stated earlier, the original data did not lend itself to phenomenographic analysis. The interviews were not carried out with that aim in mind and the fact that different researchers could be speaking of distinctly different sorts of research in different research situations and traditions meant that the phenomena of which they spoke could differ somewhat from one another. Here, though we have four dimensions of trustworthiness which we, through our preliminary thematic analysis, have constituted as concerning four aspects, or separate and distinct phenomena, associated with the experience of trustworthiness.

Stage 3. Appraising trustworthiness – a phenomenographic analysis of themes

Each of the four themes identified in the data, associated with four aspects of appraising trustworthiness, can be seen as a dimension of meaning with discernible variation[3]. In other words, we can consider trustworthiness to be experienced by the physicists in terms of, in the first place, four aspects, and in the second place a qualitative variation of meaning in each of the aspects. We will now describe the results of our analysis, the variation of meaning in each aspect being briefly described and illustrated by extracts from the interviews.

What is trusted? – The figure of trustworthiness

When appraising whether or not something is trustworthy, there is something which is spoken of as figural – the object of appraisal for trustworthiness – having certain delimitations and characteristics, and which can be described in terms of two categories. They are:
- trusting a *specific* object or feature of the research work, and
- trusting a *system* of specifics, and the relations they have to each other in the

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[3] From now on, such a dimension with discernible variation in meaning will be called a "dimension of variation" in line with phenomenographic praxis.

system.

In the first category, the specifics found in this study are typically some measured pieces of data or calculated results, extracted from the whole research effort for special consideration. In the second category, a figural object of trust can be, for example, a model, a line of argument, a full analysis and its implications, an understanding of a physical phenomenon or a world view. A system may be constituted of specific elements of, for example, measured data and calculated results, where a pattern of intelligibility is attached to the whole as well as the specifics

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The following extract is an illustration of the first category where the object of trust is the result of a calculation, which is treated on its own terms:

P_{15} *I mean if you have seen things that are, if there are certain results that have been tested and measured and then you want to do calculation and you find that they don't, your results don't agree with experimental results then something is wrong, somewhere.*

The object of trust is compared with a measurement, another specific, which has been tested appropriately.

That in contrast to the following illustration of the second category, trusting a system of specifics:

I *These results that you have got so far do you trust them?*

P_5 *Do I trust them? I trust the formal expressions, yes. (Ok) And why do I trust my formal expressions? That should be your next question. I trust it because I can see that some limits come out...*

Here, a trust in some specific formal expressions, is also voiced, similar to the extract from the interview with P_3. But, then, the specifics are immediately related to other objects of trust, through "taking limits", and thus implying trust in the origin of the calculation, the model and the world view in which they were produced. Such an interpretation is supported by the following discussion with the same person, which took place after a detailed consideration of the aforesaid limits:

I *That is that you trust your results in relation to your definitions and the formal expression, but trusting your result and the validity compared to the physical problem?*

P_5 *Aha, ok. If a courageous experimentalist comes along and builds the thing will she see what I have predicted that she will see? That is a harder issue, because we know that when we set up the model we make some approximations. The basic approximation here is this approximation of short-range interactions which is not perfectly well justified. However I think that it captures qualitatively the right physics so the numbers may not come out right but the features should come out right.*

In this part of the discussion, it is also clarified to what extent and in what sense the specific results are trustworthy. They are trustworthy within this particular model, and are to be interpreted, as a description of the essentials in the physical situation of interest, and the features of the model itself is an abstract object, to be trusted because of its relation to the physical situation of interest.

What is trusted? – The context of trustworthiness

Trust is spoken of as being appraised in a context, in which we have found variation

with three distinct meaning values which successively extend the bounds of the context of in terms of who, where and when:
- considering only *me and my work*, here and now,
- being a part of a *local network*, typically within the research group and their established "friends", taking place now but extended to here and there in extent, and
- acting within a *global network* of physics and physicists including a historical dimension, which takes place both here and there, extended temporally to now and then.

In the following extract P_{13} discusses trusting his own results. The focus is on his work here and now, being the single person involved in the coming to trust the results. Influences from the outside, such as theories, are reduced to 'existing' without a context, or taken to be fixed points.

I   *Ok, yeah. When you do measurements on systems like this or when you are going to do. What will make you trust your measurements?*

P_{13} *...I guess it's this standard idea that you are expecting a certain result because you have a theory, which predicts this and then you, so you compare your results with the theory you have and hopefully they will agree and the theory should be able to predict new things so then you change your settings and then you do these experiments too and theory and if that agree you have reasonably good idea that this, it might be working. But of course also you have to consider all other possible effects that might give the same results.*

The focus of the extract below is on the interviewee P_{16}'s own situation. When the interviewer brings up the general difference between doing experiments and theory, the focus is on what P_{16} is and should be doing.

I   *What do you think is the difference between doing experiments and theory?*

P_{16} *... Experiment is, should be, I feel that I should be better in theory when I do experiments, because I think I can gain more from the measurements, then there is two things to learn at the same methods, it's getting very much...But theory I see as the understanding and experiment is to know how to do it, in principle, that's to try to get a good mix between those two makes you a very good experimentalist, I think. Because if you can measure something and actually see the connection directly that would improve your further schemes.*

The second category or meaning value, to rely on a local network, is illustrated with the following extract:

I   *How do you decide what kind of research results that is reliable?*

P_3 *That's a sort of, that's easy. One, you trust results that you could that you would have expected, that are not controversial. And B), you trust results from groups that you know about.*

Within the local network, here "groups that you know about", it is implied that most things are trustworthy. P_3 also points out that results that are expected, and thus easier to relate to experience, are easier to establish trust for.

In the third meaning value, to contextualize trust in a global network, several interrelated aspects of actions are brought up, here illustrated with an extract from the

interview with P_{14}, which is a part of the extensive extract in the section on the complexity of trust:

> P_{14} *I can see some people are taking measurements and publishing the measurements and not saying very much about the interpretation of the measurements and I try not to do that. In some cases I have to do that because I have no explanation but then I don't, then it's a conference paper and I sort of publish that to make it known to the rest of the community that this measurement has been done and maybe some theoretician is interested and they might find an solution to it, but I think to make a really good paper I think one should really explain why the measurement data looks the way it does, why it depends the way it does under certain parameters ...*

The discussion takes up, on the one hand, disadvantages of publishing measurements without analysis, and, on the other hand, situations when that might be necessary, allowing a detailed consideration in each case. To really trust the data, and make it into a "really good paper", more foundations for trust must be brought out, by the researcher himself or by the community.

How is trust established? – The anchor of trustworthiness

The way in which the interviewees talk about appraising trustworthiness of different figural objects, primarily concerns relating the figural object to elements of different kinds, which it is not necessary to question. It is as if by being associated with these elements, whose trustworthiness is in some way guaranteed or taken for granted, the figural objects become trustworthy in turn. The elements lending trust to the figural objects can be classified as being anchored in either:

- formal physics,
- the community of physicists

In the same appraisal, the figural object may be anchored to different aspects of these, and whether formal physics or the community of physicists, the anchor can be ideal or relative.

Anchoring trust in formal physics can entail reference to specific "givens" of the field of physics, as an ideal to adhere to, or possibly to acknowledged good work or good published papers, or to philosophical underpinnings such as parsimony or symmetry. In the following extract, the ideal of good physics is discussed as related to the quality of their publication:

> I *Ok. So what is then good physics?*
>
> P_3 *I mean there I have to trust the, it's sort of iterative. One thing is that good physics is published in good papers, in good journals, and then of course you are not interested in other things that are published in good journals ...*

P_3 continues:

> *...so what's good physics is sort of determined by people that you talk to. It's of course; my idea of good physics is very much inspired by X's [4] opinion and your opinion and Y's opinion, and the people around me. [...] So I don't see that good physics is like a really objective [thing], I mean it's: My opinion about good physics depends on me.*

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4   X, Y, Z etc are used when other researchers are referred to.

> I   *So basically my opinion of good physics could be something else?*
>
> P₃   *Yes, I guess that most people have slightly different opinions, I mean, yeah.*

And there his anchor has switched to the community, in a local sense, has come to the fore.

In the following extract, P₃ anchors trust in a personalized way to a researcher in the same group:

> I   *Yeah ok. And you trust his experiments?*
>
> P₃   *Yes I, he seems to be a very good, he does good experiments and he has a very profound understanding about what he's doing so you can always ask him how does this work and he can tell you. (Ok) He may not be able to tell exactly how that Hamiltonian term does work. I mean tell, he can tell you in picture what is going on.*

In the next extract, P₁ , having apparently related his trust in his research to features of formal physics – the literature and the results from closely related fields – goes on to anchor his trust in the community in an impersonal sense:

> I   *Ok the, you said that you to get some idea of this parameter that you are using: mass and length and so on, you look in the literature and you talk to experimentalists and so on, but how do you decide what is worth to, which experiments to try to understand and which measurements that are good and what kind of literature writing that is trustworthy in sense of which one could you use?*
>
> P₁   *Well I haven't seen any great controversies in these things. I think people pretty much agree on what's typical diameter, typical length of the tube and I have seen so far only one paper which measure impedances of theses tubes and it's the one I've been using so far. Some things are quite established in the sense that there's been written a book haha. It's a pretty safe place to look.*

If the community thinks something is all right, then it is trustworthy

How is trust established? – The quality of appraising trustworthiness

Appraising trust may be described as a more or less complex process. In the data there was variation which can be described as two categories:

- forming a single relation in form of an isolated criterion,
- forming a network of relations or reasons, having relative strengths, giving a total strength to the trustworthiness of the object.

The quality can be single and binary, without connection to other criteria, or multiple, relational and connected. The character of criteria, whether single or multiple, are of different kinds, for example, checking that the results behave "correctly" in limits, an aesthetic value, symmetric formulas and measurements, and repeatability.

The appraisal can be anchored to trustworthy elements of different kinds, in formal physics or the community of physicists. Connecting it to the body of formal physics means to relate it to other parts of physics through criteria or to one's experience of how "physics" usually works. Connecting it to the community, means that these people think this is trustworthy, or they are involved in similar activities.

In the extract below, an illustration of the first category, focus on the agreement between theory and experiment is the sole criterion for trustworthiness, and is isolated from other considerations.

> I   *Ok, yeah. When you do measurements on systems like this or when you are going to do. What will make you trust your measurements?*
>
> P_{13} *...I guess it's this standard idea that you are expecting a certain result because you have a theory, which predicts this and then you, so you compare your results with the theory you have and hopefully they will agree and the theory should be able to predict new things so then you change your settings and then you do these experiments too and theory and if that agree you have reasonably good idea that this, it might be working.*

Similarly, in the extract below, the agreement between experimental results and calculations are taken to be the sole criterion for trustworthiness, otherwise "something is wrong".

> P_{15} *I mean if you have seen things that are, if there are certain results that have been tested and measured and then you want to do calculation and you find that they don't, your results don't agree with experimental results then something is wrong, somewhere. The object of trust, the calculations are related to the agent of trust: agreement with experimental results, which is an absolute ideal. The relation is of a single and absolute nature: either the criterion for trust, the agreement, is fulfilled or not.*

In the following discussion of what lends trust, a network of relations to people and their activities in physics is put forward as constituting the relation between the object of trust and the agent that lends trust, though entailing a risk, thus offering an illustration of the second category:

> I   *Do you trust the results that you have?*
>
> P_2 *Yes.*
>
> I   *Ok, why?*
>
> P_2 *Because I have, because what other people have done before, so I rely on that that is ok, so I, people sort of define some effective Andreev reflection amplitude, but that is more or less what I have done too. So with discussions and what I have heard from other people this will be ok.*
>
> I   *So this is what people tell, in general and then it's ok?*
>
> P_2 *Yes. So in a sense I trust what people have done before, which is dangerous, but I think it's ok.*

Similarly, in the next extract, the establishment of links to a network of physics through a set of inter-related criteria is discussed:

> P_5 *And why do I trust my formal expressions? That should be your next question. I trust it because I can see that some limits come out right for instance I can take the limit of getting rid of the mechanics by choosing some parameters equal to zero and then I will get the standard result that is already seen. That is one aspect. There is another aspect that the result should look right, so the esthetic argument that caused me some headache yesterday [...]*

Thus while all these discussions of trustworthiness relate to certain criteria, what distinguishes the first category from the second is the degree of connectedness – from unconnected to multiply connected.

Discussion

Summary

In summary, Table 1 shows the four aspects of establishing trustworthiness in physics work, whether one's own work, or that of others, that have been identified. Each is constituted of a dimension of variation, and the scope of these dimensions has been discerned.

What, figure, object	Specifics System of specifics
What, ground, context	Me and my work, delimited to here and now The local network, extended spatially The global network, extended spatially and temporally
How, anchor	Formal physics Community of physicists
How, quality	Single, unconnected, binary criteria Multiple, connected, related criteria

Table 1: Summary of the variation identified in the four aspects of trustworthiness.

In each of the four aspects, the categories described are of increasing extent, which does not mean to imply that they are of increasing importance or value. However, it does mean that for a well-balanced evaluation of the quality of research results, there is a broad framework within which narrower concerns can be considered. Considering the results at an individual level, it can be said broadly that the less extensive ways of experiencing the appraisal of trustworthiness arise from interviews with the less experienced researchers (graduate students) and the more extensive from post-doctoral researchers and professors[5].

The whole of appraising trustworthiness in a case

Let us return to the interview with P_{14} that we opened with, and analyze it more carefully in the terms now introduced. In response to the question on whether he trusts his results, P_{14} offers a complex discussion, in which he coherently relates to all four aspects discussed in this paper.

When he says:

> *you really need to verify over and over again in experiment that you get the same result*

it is a reference to the specific result under consideration, the figure to which his attention is directed, but when he qualifies that, saying:

> *and you also have to look for possible errors or some impossible parasitic effect that you might not think of*

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[5] A more detailed analysis of the provenance of the categories would risk exposing individuals, in contradiction to our promise of anonymity.

it is a reference to the figural system within which the specific is to be considered. There, he is placing the figure against a ground of "me and my work", but goes on to extend it to the global network that might have use of his work:

> *I sort of publish that to make it known to the rest of the community that this measurement has been done and maybe some theoretician is interested and they might find a solution to it*

"What" he is focusing on as being trustworthy is thus covering the scope of our analysis in terms of figure and ground.

Both formal physics and the community of physicists are referred to as referential anchor in the process of appraising research, when he refers to his own formal physics analysis and theory on the one hand, and his own reception of the results of other physicists on the other hand:

> *I think really it's important you that have some degree of analysis and theory of your results so that you can, I can see some people are taking measurements and publishing the measurements and not saying very much about the interpretation*

And while a specific result has to be verified to ensure its quality:

> *I think to make a really good paper I think one should really explain why the measurement data looks the way it does, why it depends the way it does under certain parameters and if you do have a coherent picture of the data*

the result he has obtained has to be connected to a broader extent of research if it is to be classified as "good":

> *reproducibility is of course the key factor, it should be made at least the same measurement on the same sample several times and of course you would like to have several samples that show the same phenomena*

In summary, trustworthiness is connected to a global community, relating a system to it. Similarly, the community anchors the appraisal of trustworthiness and is the arena where trust is established. It is established using a set of different criteria, which connects to a network of other people and their activities and to a network of his own as well as to the network of people's experience of the physics.

The way in which the researchers discussed trustworthiness did not only vary in the ways in which they discussed the different aspects, but also which aspects were brought up (some were absent in some cases) and if they were brought up separately or coherently. This implies that there was a meaningful variation in how the phenomenon trustworthiness was present to the interviewees, not just in the different aspects, but in the whole, as implied by the three broad preliminary categories presented at the outset.

The summary in Table 1 can also be expressed as a simple tree diagram where the experience of appraising trustworthiness is analysed into two intertwined aspects – what and how – which are in their turn analysed respectively into figure and ground, and anchor and quality, as in Figure 1. This shows clearly the general underlying structure: from the specific, isolated and absolute to the multiple, related and relative, from the individual to the community, from the local to the global.

It has been mentioned that there was a trend for less experienced researchers to express

themselves less inclusively than the more experienced researchers did, which brings up a pedagogical and didactical issue: how to extend the breadth of view of doctoral students and thereby strengthen their capacity for evaluating their own research and that of other physicists? We now go on to suggest two features of physics as a research activity that can be emphasised in doctoral education and in supervision in order to bring trust in research into greater focus than merely relying on repeatability of experimental results and the formal correctness of theoretical results. For physicists, like any other research field, have specific and general interests in common and form communities with various mechanisms to lend identity and membership.
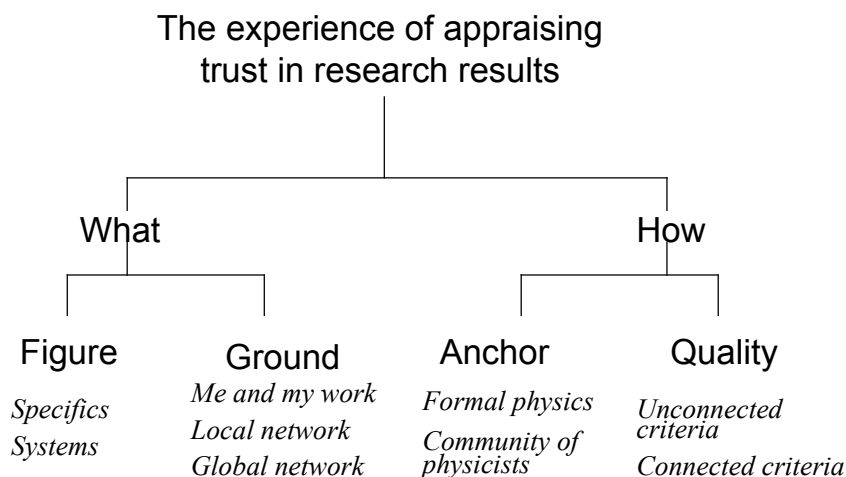

Figure 1. The structure of experience of appraising trust of research results

Participation in a community of physicists

Apparent in P_{14}'s discussion is a sense of participating and relating to a community, in which the whole drama of the research and its establishment takes place, and in which he plays a role. The community of physicists involved in a particular physics research area may be seen as a community of practice, discussed by Wenger (1998) among others in the sociocultural tradition. Wenger (1998) discusses a community of practice in terms of the central terms participation and reification, which he proposes as the two elements that constitute practice. Participation means:

> *"Participation refers to a process of taking part and also to the relations with others that reflect this process. It suggests both action and connection. In this book, I will use the term participation to describe the social experience of living in the world in terms of membership in social communities and active involvement in social enterprises." (Wenger, 1998)*

So in this sense participation is not merely "being there" or even "doing the same things as the others" as participating in a meeting might be, but it is also being in relation to other members of the community and the acts that are played out there.

He uses the term reification to denote a concretization of abstract concepts, values and actions:

> *I will use the concept of reification very generally to refer to the process of giving form to our experience by producing objects that congeal this experience into 'thingness'. In so doing we create points of focus around which the*

> *negotiation of meaning becomes organized. (Wenger, 1998)*

So reification, in this sense, can be as simple as filling in a tax form to confirm your family's financial transactions over the past year, or as complex as codifying the constitution of an emerging democracy. Wenger's model of a community of practice, in which identity is established in a learning process of entering and establishing oneself in the community, is complex, but the same sort of model can be applied to the physics community, or its specializations, with its newcomers and its masters.

The peer review process may, on a general level, be seen as formalized (reified) negotiation of meaning around a reification of research participation (an article), which is meant to serve as a guarantee of the trustworthiness of the research done. On the other hand, on the local level of the individual researcher, refereeing is an action which is connected to participating in the community of physicists. The content of the publication is in turn a reification of the understanding brought about through the corresponding research work.

Here an interesting distinction can be made between local and general participation in practice. Local participation happens through discussing and personal interaction. Global participation happens through sharing publications, reifying understanding and results in text on what has been done. And trustworthiness is an important two-way relationship between local and global connected through the production and refereeing of papers.

In the interview data, it is interesting to see that some of the interviewees articulate a participation in the community, as P_{14} does, while others seem to be unaware of the possibility of participating in the general community, more common among doctoral students than their more experienced colleagues. To be aware of and to consider the community, and to see oneself as participating in it in making judgements, might be seen as a mature way of handling trust, though there is not enough empirical evidence to make such a strong claim here. When one of the more established researchers, P_1 (cited earlier), says "Well, I haven't seen any great controversies in these things. I think people pretty much agree on what's typical […] some things are quite established in the sense there's been written a book" he is showing such an awareness of a community, reified in publications, since it is not feasible for interactions at a personal level in the community of such a large field as mesoscopic physics.

Establishing a community through reified "gossip"

Implicitly, informal interaction is referred to as an important aspect of how research results are established. For example P_3 and P_{14} refer to their discussions for making one another trust their results. Also more distant forms of interactions take place. P_4 points to an informal network of "gossip" (Traweek, 1988), which his professor takes part in, where research results are announced and established long before publication, through a network of research friends.

> *I*   *Is that the picture that you have of how knowledge is spread within the community, among, is that mainly through conferences and partly through articles?*
>
> *P_4*   *What I've seen is that there is a network of physicist. Let's say Z, Z my professor. He usually gets mail from all over the world. From his, how should I say, research friends all over the world. Asking him to: Well, I've seen this article, could you comment on that, we've discovered this, could you comment*

> *on that. And that is, sometimes, he forwards those mails to us, if it's something interesting. So there seems to be another channel, which I wasn't aware of before I started my PhD. I thought that conferences and articles were the, and of course discussions, which is kind of conference like, were the main knowledge transmitter, is, but there seems to be channels of science friends that are communicating science to each other, I mean we found this, we found that, they found this, they found that.*

I   *It's sort of research gossip?*

P4   *Yeah, kind of research gossip. That seems to be, to me it seems to be a very important way of transferring knowledge, even though I'm not myself very deeply involved in any of those.*

I   *You connect to that through your professor?*

P4   *Yeah, through my professor*

This links to some of the findings of Traweek (1988), who claims that social activities like (research) gossip is an important part of the research activities without which the researchers cannot do good physics. However, this activity is not recognized as important by the physicists, who write publications in a different way.

> *The question remains: why don't they write what they say? If gossip is a means of producing physics, physicists, and their culture, then written materials, articles and preprints, are the commodities the physicists produce in their turn. Articles represent the consensus, the 'facts,' data with the noise removed. The authors of these written accounts own the information in the account. Any subsequent users of that new information must pay royalties to the authors in the form of homage or credit, thereby increasing the accumulating reputations of the authors. In talk physicists rarely give credit to others. Scientific writing keeps track of the results of these debates. It is a record-keeping device, a spare ledger of credits and debits. Citations are a trace of something happening elsewhere, as a bubble chamber photograph presumably records traces of events in subatomic nature. (Traweek, 1988)*

Interestingly, in the last decade electronic publication on the "Los Alamos" preprint server[6] has become an important way of announcing physics research results, in particular for theoretical work. One is free to publish articles on this server and they are not refereed. During the first author's time as a Ph.D. student in the neighbouring field of microelectronics and nanoscience, it was part of the daily routine to take a look at the Los Alamos-server and was (and is) a way of keeping up to date with the latest research. Similar routines are expressed by several interviewees and many other colleagues, and it serves as an anonymous formalized distributor of "gossip" or as a continuously ongoing conference. Results that are only published there are treated with some care, and are seen as preliminary to a much larger extent than results published in ordinary (high-status) journals like Physical Review B and Physical Review Letters, where the ideal to meet is seen to be of high standards and the refereeing process is recognized as generally reliable. And that links back to trustworthiness as something being established through a process of participation and reification of the participation.

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[6]   http://arXiv.org/

Implications

A physicist is constantly making judgments about the trustworthiness of his/her own work as well as others. This is an essential aspect of what it means to become a physicist. The thrust of this paper is that trustworthiness is handled in qualitatively different ways, some more extensive and inclusive than others, and that in order to become research physicists, doctoral students need to be brought into the broader community of physicists with research friendships and gossip as mechanisms.

A Ph.D. student embarking on becoming a physicist will have to, apart from learning about physics phenomena and formalisms in his/her research, develop a way of handling the appraisal of the extent to which research is trustworthy. In that process, different objects of trust – specifics and systems – are to be seen within different contexts – networks of different extent, anchored in formal physics and the community of researchers with different degrees of connectedness. To develop such capabilities it is important that supervisors, who have the general responsibility for the Ph.D. student's development into a full-fledged researcher, continuously engage the Ph.D. student in such considerations, bringing to the fore not only whether something is to be trusted or not, but also engage in discussions of why it is to be trusted or not, and bringing them into their own arena of the community.

The way forward

This work is entirely empirical in nature, relating as it does to the ways in which trustworthiness of physics research is expressed by physicists themselves. There are a number of fields of knowledge that could deepen and widen the work, and which deserve further consideration. Not least among these is the writings of philosophers of science such as Popper and Kuhn and their considerations of what constitutes valid knowledge. The anthropologists and ethnographers such as Latour and Traweek, who was touched upon briefly above, have studied communities of scientists and how they relate to one another through their research and trust in it, and relating these results to that field would be profitable. Wenger has also been touched on, and his writings on the nature of learning and the development of identity in communities of practice has much to say about the structure of the results we have described here. All in all, very little work exists having an education thrust such as developed in this article, and it deserves more attention in the emerging knowledge society.

Finally, the empirical work itself could be valuably extended by conducting a similar but more closely focused study with a larger number of researchers at different stages of their careers, now specifically asking about the nature of trustworthiness but with an educational thrust, engaging in discussion about one's own development as a physicist and what one desires for one's students. This would enable, first, the question of maturity and developing maturity as a researcher to be brought into focus, second, the relation between ideology, as articulated by philosophers, to be brought into relation with the practice, as expressed by the practitioners, and third, the results to be brought to the attention of research supervisors.

Conclusion

Empirically based descriptions of aspects of appraising trustworthiness, and the variation of meaning to be found in those aspects, have been given based on a study of ten physics researchers. In general terms, the variation shifts from trust being

established with respect to an isolated criterion of absolute nature, anchored in a single person or feature of the work, in a local context, to it being associate with a system of criteria embedded in a community of physicists, or a network of features or ideals in a more global context. More work needs to be done in order that the results can be brought into practical pedagogical use for the good of doctoral education in physics research, and possibly to contribute in general terms to research training in other science and engineering fields.

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