Critical reflections on temperature change

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Advanced mathematics often plays an important role in risk evaluation, for example in relation to climate change. How can mathematics related classroom discussions enhance critical citizenship when societal issues are accompanied by advanced mathematics? In a master course in mathematics didactics, a figure from IPCC was discussed. The figure shows developments of the average global temperature changes. In this paper, we analyse the classroom discussion in accordance with Skovsmose's six reflection steps, with focus on societal aspects. The students reflect critically on the data used to support the figure, on characteristics of the models, on the models' significance in society and on their own participation in the classroom discussion. We discuss the results in a broader educational and societal context.

Keywords: Critical mathematics education, climate change, reflective knowing.

INTRODUCTION

Mathematics often plays an important role in risk evaluation as support for policy making, for example in relation to climate change. However, risk issues are often associated with complexity, uncertainty and conflicting stakes, which implies that mathematics supporting political decisions is advanced, but also associated with uncertainty (Funtowicz & Ravetz, 1993). A consequence of this uncertainty is that mathematics based arguments can support opposite political stances.

This is in line with Skovsmose's claim that mathematics has a formatting power in society in that it influences how reality is perceived (Skovsmose, 1992). He further argues that the ability to recognize this formatting power, and reflect on it, is an essential democratic competence in order to balance the experts' influence on politics and society. He refers to this ability as reflective knowing. The role of offering critique to experts and politicians on societal issues can be denoted as critical citizenship (Jablonka, 2003). Mathematics and science educators offer perspectives on what critique may signify in relation to the issue of climate change in education. Barwell and Suurtamm (2010) argue that the mathematising of climate change makes human activity invisible and call for more visibility in the modelling process, for example through information on model assumptions to help evaluating whether the model fulfils its purpose. They suggest that mathematics education has a responsibility in facilitating reflective knowing on the role of mathematising climate change and call for research within the area. Barwell (2013) further supports these arguments by showing how a particular philosophy of science matches ideas from critical mathematics education, as for example the formatting power of mathematics, reflective knowing and critical citizenship. Hansen (2010) discusses what critical democratic competence might be in relation to predicted sea levels as an effect of global warming. As Barwell and Suurtam, she links this to the modelling process and underlying assumptions, and her emphasis is on mathematical modelling as a classroom activity to prepare students for future critical engagement in such issues.

All these three papers are theoretical papers and include the idea of mathematics education as a preparation for critical citizenship. Although they suggest various student activities for enhancing reflective knowing, they do not suggest how this reflective knowing may be expressed when facing claims developed through advanced mathematics of climate science. Looking to science education, Erstad and Klevenberg (2011) describe a classroom study where the student task was to explore topics in "An inconvenient truth" with Al Gore. The aim of the task was to learn about aspects on science in society. From searching the internet, the students discovered that certain controversies on climate change were linked

to disagreements between scientists. The paper thus addresses complexity in climate change through expert disagreements.

The issue of climate change may be too complex for students to develop alternative mathematical approaches that can pinpoint socio-political consequences of mathematized information. A crucial area of research would therefore be on what kind of critical reflection non-experts can provide on advanced mathematized information that is useful for critical citizenship.

In our study, students of a master course on mathematics education discuss a figure (Figure 1) taken from a report by the Intergovernmental Panel on Climate Change (IPCC, 2013) as an introduction to critical mathematics education. The authors of this paper are five of the master students and the lecturer. The IPCC graph presents different modelled courses of average global temperature changes. The mathematics supporting the graph is far too advanced for the students and the lecturer to grasp. Still, can reflecting on the graph enhance mathematical understanding that is useful for critical citizenship?

The research question of our study is: 1) What kinds of reflection related to critical citizenship are expressed during the classroom discussion on the IPCC graph? In the following, we describe the data and present Skovsmose's (1992) six reflection steps, which we apply to our data analysis. In the analysis part, we follow the course of the classroom discussion and offer examples of expressed reflections. Finally, we discuss the significance of our findings to critical citizenship.

DATA AND METHOD

As an introduction to critical mathematics education in a master course, the nine students and the lecturer (Kjellrun) discussed a graph produced by IPCC on predicted temperature changes (see Figure 1). The discussion was followed by a lecture on selected literature from critical mathematics education, where links between the initial discussion and the literature were collectively drawn. The lecturer chose this figure because of its potential for generating reflections about mathematics and its use: (1) its political relevance and dispute, (2) it expresses uncertainty through statistical spread, different pathways of future emissions and implicitly through dissenting model results, (3) the social construct of "global average surface temperature" and (4) the problem of measuring temperature in space and time. Her intended role was to keep the discussion as student driven as possible, but at the same time ensuring that student reflections took place. Before the discussion, the lecturer invited the students to write an academic paper on an analysis of their discussion together with her. The analytical tool to be applied was part of the curriculum. Five of the students accepted the offer and are co-authors of this paper.

The classroom discussion is analysed by using Skovsmose's (1992) six reflection steps, of which five are later picked up by Gellert, Jablonka and Keitel (2001) and referred to as five reflection levels. The steps can be summarised as reflections related to the following questions: (i) Are the calculations right? (ii) Was the right algorithm used? (iii) Is the mathematical approach reliable? (iv) Could the problem be solved without formal mathematics? (v) How does the mathematical approach affect the specific context of the problem? (vi) Could we have reflected on this in another way? The six reflection steps refer to what Skovsmose calls steps towards reflective knowing and which is essential for critical citizenship. They represent steps of students' reflections while engaged in problem solving.

The first pair of steps refers to reflective thinking within pure mathematics, the next within applied mathematics and the latter within a broader, societal, understanding of mathematics (Skovsmose, 1992). As these reflection steps are developed for situations where students reflect on their own problem solving, in contrast to our case, we have adjusted the reflection steps for our purpose. We have chosen (i) and (ii) to include our reflections on the mathematics expressed in the graph, which are developed by others. Since the underlying mathematics is hidden for us, we have concentrated on our understanding of the graph contents, for example: Have we understood the graph correctly? Have we understood underlying algorithms? We consider such reflections as a required basis for reflective knowing and critical citizenship and are therefore relevant to include in our analysis.

The two classroom discussions on the graph and on applying the reflection steps on the graph are audiotaped. Additional data include notes and the lecturer's PowerPoint presentation. We have applied the

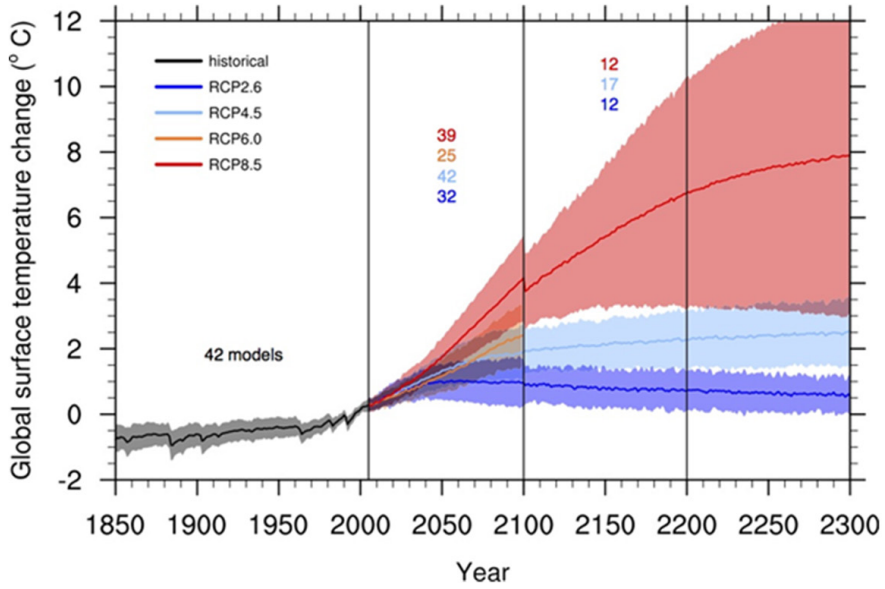

Figure 1: Temperature change. The graph shows modelled developments of the global annual mean temperature change (IPCC, 2013, p. 89). The change is calculated relative to the period 1986–2005. Four future scenarios are presented with mean (the coloured trajectories) and 90% confidence interval (the coloured shadings). The colours represent different possible emission levels of greenhouse gases (RCP – representative concentration pathways), which will depend on today's and future global climate politics.

authors' names in the excerpts. The other names are anonymised. The audiotaped discussions were transcribed and coded by the students in accordance with the six reflection steps. The coding turned out to be challenging as the steps were not straight forward to apply. This was discussed during meetings.

ANALYSIS

In the following, we present some excerpts from the classroom discussion, which we analyse in accordance with Skovsmose's six reflection steps. The beginning of the discussion was dominated by the students making sense of the figure (Figure 1): the general features, the significance of the colours, the lines etc. Repeated words are deleted in the excerpts. The first excerpt takes place early in the discussion.

Tor Inge: Where does the limit go for where the measurements fall within?

Maria: It depends on which scenario is taken into account. If they have calculated with an RCP value of 8.5, and that resulted in. Those who achieved the lowest values at the lowest one, right? And then they calculated with the same model with a value of 2.6. And that could have resulted in one of the lowest values there. While some with a high value could have ended down there. What you can see here is that there's a lot of variation here. That here it seems that they disagree much more.

Tor Inge: More uncertain?

Maria: Yes, while at the blue, they quite agree all the way, in a way. They are more certain.

Tor Inge seems to misunderstand what the colours represent, as "limit" may refer to dividing mathematical model *output* into colour categories. Maria responds by explaining that the colouring depends on the *input* of the model, "which scenario is taken into account", determined by specific RCP values (see Figure 1 for an explanation). Further on, she offers a reason on why the shaded areas vary in magnitude: "they disagree much more." When Tor Inge asks "More uncertain?", he is probably asking whether Maria refers to the spread in the graph, or uncertainty.

When Tor Inge asks his first question, he is probably seeking to understand the graph, which can be categorized as Skovsmose's reflection step (i). Indirectly, Maria expresses that the figure is based on several models that do not produce the same results. The students do not discuss further what this disagreement implies, for example how and why the models are dif-

ferent, the reliability of the various models or whether such disagreements can explain why there are climate change deniers. This means that the excerpt has onsets to Skovsmose's reflection step on reliability (step iii) and on implications for society (step v).

The next excerpt is taken from a part where the students discuss natural temperature fluctuations, exemplified by ice ages. Tor Inge has expressed that he would have liked to know more about the temperature back in time.

Tor Inge: Yeah, I would have gone further back in time, and seen. We talk about they only are natural fluctuations, which also have taken place before, right? And how high were the peak temperatures longer ago, before the measurements?

It is likely that Tor Inge imagines that knowing "the peak temperatures longer ago" would have strengthened his confidence in that the temperature development after year 2000 is extraordinary. Since Tor Inge is addressing the reliability of a conclusion drawn from the graph, we categorize his utterance to be a critical reflection in line with Skovsmose's step (iii). However, the reflection can also be denoted as step (v), since the utterance may suggest that a different mathematical approach could have affected his perception of climate change.

In the following, Kjellrun draws the students' attention to a specific feature in the graph.

Kjellrun: [...] But if we look at year 2100, what is happening there? [pause 16 sec.]
Anne: [inaudible] is a shift?
Kjellrun: Yes, why is that?
Anne: At least the red one.
Kjellrun: Yes, at least the red one, that's very distinct.
Anne: There are fewer models, you know.
[...]
Tor Inge: I'm thinking that the most critical until 2010 do not continue further in the models, [Kjellrun: Yeah, well that's true.], so that the curve isn't as steep when it continues.

The combination of Anne pointing to that "There are fewer models" and Tor Inge stating that "the most critical" models "do not continue" after the drop, suggests that Tor Inge reflects on how the prediction results depend on which models are used. We assume that Tor Inge means 2100 and not 2010, and we interpret "critical" models in this case to be the models predicting greater and more dramatic temperature changes. Anne's statement that "There are fewer models" can be denoted as reflection step (i), as she seems to be in the process of making sense of the shifts in the graph. Tor Inge's remarks can be categorised as questioning whether the right algorithm was used in selecting models (step ii), whether the approach is reliable (step iii) and whether the selection of models affects the perception of the severity of the problem (step v).

Later, Kjellrun asks about the relevance of graphs like the one we had discussed:

Kjellrun: Has it had an impact? Have the climate panels' - I guess we can call it warnings?
Terje: Maybe routines and control measures have become stricter?
Anne: I'm thinking about the discussion he had with Vesterålen and Lofoten. The loss of oil. This model may influence whether in fact there will be oil production there, because you can see what oil production causes.

Terje and Anne (and other students) suggest various impacts of the graph, or maybe IPCC graphs in general, and thereby argue that such graphs do have an impact on society and has certain potentials. Anne is probably referring to the Minister at the time ("he") of the Ministry of Petroleum and Energy in Norway, who was in favour of oil exploration in the Vesterålen and Lofoten area. In the continuation of this excerpt, the students also reflect on how IPCC has had limited influence, for example in regard to the Kyoto Protocol. Since these reflections link the graph to societal aspects we characterise them as Skovsmose's reflection step (v), although the students declare that mathematics makes a difference rather than discuss how the mathematics influence ways of understanding.

Towards the end a student started reflecting on the discussion:

Andreas: Well, I thought that we were trying to find shortcomings or flaws in all statements, on the graphs you have shown

us. That we have been very, well, very. Don't know if we've been negative, or ...

Theodor: Are receptive to flaws in the models. [Andreas: Yeah. Yeah.]

Tor Inge: We had that starting point all the time. I'm thinking about that the headline for the lecture is "in a critical". [Andreas: Yeah.] I imagine this [Theodor: Yeah.] goes into that direction.

Andreas: There have been few positive arguments for the things that have, the statements, on the graph. There have been few arguments on that they are right or that it is correct, and, on, of the researchers, of the. Yeah. ...

Kjellrun: So, we have, in a way, been looking for shortcomings or flaws? Or how it was expressed? But *are* there shortcomings about what the climate panel does? So, is our critique completely unreasonable?

Anne: No, but you know, it's. When saying that there's a 95% probability, for example. That there's a great divergence here. That maybe that's why you become so critical?

Marius: The critique has shed light. That, the critique, by closer inspection, then this critique will strengthen, you know, the findings, or what I should call it. Not the findings, the prognoses. That if we investigate further, we'll read more what was done. Then we maybe: how often do they measure the temperature, right? You know, we find: "Yeah! They do the measurements quite often, which means that they have quite accurate prognoses". Then this would strengthen this graph. That, when we take a critical stance, it can also strengthen our impression. It's hard to explain. That they, what we read here is. We believe it, maybe, [Kjellrun: Uhum.] that when being critical, you can. Difficult to explain.

Several of the students express unease about having been critical during the discussion. For example, Andreas says "we tried to find shortcomings or flaws" and expresses a concern for having "been negative". When Tor Inge suggests that the topic of the lecture may have influenced the critical stance, he too indicates that they might have been too critical. When Anne points to the "great divergence" she may be suggesting that the lack of certainty to be an explanatory factor, although her reference to "95%" is unclear. She is probably referring to the 90% confidence intervals in the figure, or she might be referring to an IPCC statement that was presented early in the discussion about human influence causing global warming. While Andreas, Theodor, Tor Inge and Anne seem to associate "critical" with negative criticism, Marius suggests that "critique will strengthen [...] the prognoses". He indicates that critique can also increase confidence in a graph. Since the students are suggesting that they could have reflected in different ways, the whole excerpt can be categorised as Skovsmose's reflection step (vi).

DISCUSSION

The analysis shows that the students reflect in accordance with most of Skovsmose's six reflection steps, taking our modifications of the steps into account. The students help each other interpret the graph, they question whether the graph supports IPCC's claim on the present situation being extraordinary and they respond to the information about the graph being constructed by a number of models and which produce diverging results. They thereby reflect on the relevance and sufficiency of the mathematical approach, and they further reflect on how the approach affects perceptions of climate change. Some students show resistance to their own critical reflections, expressing them to be negative, while one of the students defends them as *critique* of the graph rather than *criticism*. The analysis suggests that reflecting together on the graph, helping students to understand its mathematical contents, was vital for the later reflections linked to the reliability and the implications of the graph. This supports Skovsmose's (1992) reasoning that reflective thinking about the mathematics itself and its application is necessary for reflective knowing.

Skovsmose (1992) further promotes reflective knowing as essential for critical citizenship. Although the students demonstrate reflective knowing, key questions remain. Do our findings show that these reflections are significant for critical citizenship? We argue that in several ways they do. We experienced that the graph was challenging to interpret, requiring insights in statistical concepts and mathematical modelling. Yet, the discussion demonstrates that although we did not have the expertise to understand the mathematics

behind the graph, the students are capable of reflecting on how the mathematics relate to its context. A key capability for critical citizenship is being able to question whether certain data are included, model assumptions and whether certain perspectives are taken into account (Barwell, 2013; Barwell & Suurtamm, 2010; Hansen, 2010; Funtowicz & Ravetz, 1993), of which all were demonstrated in the discussion. On the other hand, the students had only onsets to expressing a connection between uncertainty aspects and the role of this uncertainty in society and policy making. The students connect uncertainty in the temperature time series to society's perception of climate change, but they do not explicitly reflect on the significance of the discrepancies between models.

This brings us to another question: What is the role of the lecturer/teacher in promoting reflective knowing? Should the lecturer have been more active in making links between the mathematics and society? She did bring the students' attention to some of the features of the graph, as for example the shift. She also asked about societal impacts of the graph. Still, she could have taken a step further and invited the students to specifically reflect on the formatting power of mathematics, as for example the significance of the shift for how climate change is perceived, how society can cope with the uncertainty they had addressed and the difference between critique and criticism in this context. This might have led to other crucial aspects of critical citizenship, as for example uncertainty in science and why there are disagreements about "facts" and how we should cope with this uncertainty (Funtowicz & Ravetz, 1993). We thus conclude that Barwell's (2013) call for addressing the formatting power of mathematics in climate change was partly achieved in the classroom discussion, but that it still had a potential that was not fulfilled.

With some amendments, Skovsmose's reflection steps showed to be useful as an analytical tool for our study. Still, they are quite broad and do not guide a lecturer or a researcher on what specific attributes of the involved mathematics that can be connected with societal aspects and how. In our case, the time series, the predictions, the spread, the number of models and the drop were significant mathematical features for the discussion. We therefore recommend the development of a framework that captures attributes of various mathematical models in society, of which students/citizens would benefit from gaining insights in. Jablonka's (2003) paper on mathematical literacy shows a potential for such a framework as she characterises a handful of mathematical model categories accompanied with their limitations.

Taken together, the classroom discussion demonstrates that students are capable of reflecting on mathematical information although the underlying mathematics is too advanced to grasp. There are various attributes to the involved mathematics which non-experts, like us, could critically reflect on. We find such reflections useful for critical citizenship because it shows that non-experts can contribute by posing crucial questions about mathematics in a given context. As a final remark, we would like to add that discussions on IPCC graphs can also facilitate learning about climate change and that there are several other ways to discuss climate change in classrooms which complement our approach. We welcome research on related issues in classrooms, spanning both primary and secondary school levels.

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REFERENCES

Barbosa, J. C. (2006). Mathematical modelling in classroom: a critical and discursive perspective. *Zentralblatt für Didaktik der Mathematik*, *38*(3), 293–301.

Barwell, R. (2013). The mathematical formatting of climate change: critical mathematics education and post-normal science. *Research in Mathematics Education*, *15*(1), 1–16.

Barwell, R., & Suurtamm, C. (2011). Climate change and mathematics education: Making the invisible visible. In M. Pytlak, T. Rowland, & E. Swoboda (Eds.), *Proceedings of the 7th Congress of the European Society for Research in Mathematics Education* (pp. 1409–1419). Poland: European Society for Research in Mathematics Education.

Erstad, O., & Klevenberg, B. (2011). Kunnskapsbygging, teknologi og utforskende arbeidsmåter. In E. Knain & S.D. Kolstø (Eds.), *Elever som forskere i naturfag* (pp. 15–30). Oslo, Norway: Universitetsforlaget.

Funtowicz, S.O., & Ravetz, J.R. (1993). The Emergence of Post-Normal Science. In R. von Schomberg (Ed.), *Science, Politics and Morality* (pp. 85–123). Dordrecht, The Netherlands: Springer.

Gellert, U., Jablonka, E., & Keitel, C. (2001). Mathematical Literacy and Common Sense in Mathematics Education. In B. Atweh, H. Forgasz, & B. Nebres (Eds.), *Sociocultural Research on Mathematics Education: An International Perspective* (pp. 57–73). Mahwah, NJ: Lawrence Erlbaum Associates.

Hansen, R. (2010). Modeller, miljø og kritisk demokratisk kompetanse. *Tangenten, 3*, 29–35.

IPCC. (2013). Figure 12.5. In Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Jablonka, E. (2003). Mathematical literacy. In M. A. Clements, A.J. Bishop, C. Keitel, J. Kilpatrick, & F.K.S. Leung (Eds.), *Second International Handbook of mathematics education* (Vol. 1, pp. 75–102). Dordrecht, The Netherlands: Kluwer.

Skovsmose, O. (1992). Democratic Competence and Reflective Knowing in Mathematics. *For the Learning of Mathematics*, *12*(2), 2–11.