Secondary Students' Evaluation of Inappropriate Strategies of Reasoning About Evidence Under a Scientific Explanation

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Abstract: This study explored potential factors that could affect the development of students' strategies for evaluating scientific evidence. Thirty-six students from Grade 7 were asked to evaluate the evidence from an investigation involving force and motion. They were shown three inappropriate responses to reasoning about that evidence. They were then asked to evaluate these responses against an informational text that conveyed the scientific explanation with Galileo's thought experiment. Participants' verbal responses to reasoning about the inappropriate responses to the informational text were transcribed and analysed qualitatively. We found three factors that influenced strategy development: the students 1) kept the conflict between the competing claims of the domain unresolved, 2) doubted the validity of the inference from the thought experiment and 3) mistakenly assessed the plausibility of the competing claims. Implications for explaining the development of reasoning about scientific evidence and for instruction are discussed.

Introduction

Scientists' use of evidence to evaluate knowledge claims is important in science and science learning. Kuhn (2002) suggested evaluating claims using evidence is the essence of scientific reasoning. The use of evidence is a central component the construction of explanations (Iordanou & Constantinou, 2015).

The purpose of evaluating claims using evidence is to judge whether a claim is correct and how certain this judgment is in light of the evidence. This requires two practices: (1) to examine the *tenability* of the claim in the face of the evidence (Zimmerman, 2007), which involves determining the extent to which the claim holds with respect to the evidence; and (2) to evaluate the evidence in relation to the claim.

Research purpose and questions

The study focused on the latter practice, that is, *evaluation of evidence from scientific investigations*, aiming to explain the development of this reasoning. Studies of the development of reasoning during evaluations of claim and evidence have found that a student's content knowledge in a scientific domain plays a role in his or her reasoning about evidence (e.g., Hergovich et al., 2010). Studies have also found that students' epistemic or meta-conceptual understanding of scientific knowledge and evidence underlies the development of their reasoning in scientific inquiry (e.g., Klaczynski, 2000; Pluta et al., 2011).

However, most existing studies have focused on the practices of using evidence to evaluate knowledge claims, models and explanations (e.g., Iordanou & Constantinou, 2015; Pluta et al., 2011), rather than the practice of evaluating the evidence itself. Furthermore, research has typically assessed the changes in one's reasoning to capture the associated strategy development (e.g., Schwarz & White, 2005). Little research has investigated the changes in one's awareness of or views on the effectiveness of individual strategies during strategy development. Therefore, it remains unclear which factors promote or hinder these changes and thus influence the development of reasoning about evidence in science.

To address this gap in the literature, the study aimed to explore factors that could affect the strategy development of the reasoning about evidence. Specifically, it sought to identify potential factors that could hinder changes in students' views on inappropriate strategies in the presence of a scientific explanation. This aim was achieved by analysing students' protocols when evaluating inappropriate responses under the scientific explanation.

The research question was: *What are students' reasons for not judging inappropriate strategies as inappropriate when confronted with a scientific explanation for evidence?* This research question asked how students responded to the scientific explanation when evaluating responses that used inappropriate strategies. Specifically, this question sought to identify the reasons why students did not change their views on the inappropriate strategies, even though the scientific explanation contradicted those responses.

Significance

We contend that the practice of evaluating evidence should be a central component in science instruction that features evidence-based inquiry. The use of appropriate and sufficient evidence to support claims has been emphasised as a key dimension of the practice of developing evidence-based explanations (Gotwals & Songer, 2013). Instruction that asks students to evaluate their misconceptions of particular domains against evidence without evaluating that evidence may encourage "blind theory change" (Chinn & Brewer, 1993).

However, as discussed, there is little understanding of which factors affect the development of reasoning strategies, especially with respect to students' awareness or views on more or less effective strategies. This research can contribute to this understanding by identifying factors that may prevent students from considering inappropriate strategies as less adequate. Pedagogically, this study can suggest the knowledge and understanding that should be emphasised in instruction to promote students' reasoning.

Methods

A sample of secondary students were asked to evaluate the evidence from an investigation of force and motion and to evaluate a set of given inappropriate responses to this evaluation. Participants were then asked to evaluate the responses against an informational text that conveyed the scientific explanation for the evidence from the investigation. The transcripts of students' verbal responses when evaluating the inappropriate responses against the scientific explanation for that evidence were analysed to identify their reasons for not viewing the inappropriate reasoning strategies as inappropriate.

Research context and participants

The study took place in an urban private secondary school in a medium-sized city in South China. 36 Grade 7 students (20 boys and 16 girls aged 12 to 13 years) participated in the study. As confirmed by their science teachers, these students had not received formal instruction on the relation of force and motion. The students did have some experience of designing and implementing science experiments (e.g., investigating the factors influencing plant growth) prior to the study. But their teachers suggested they had no experience in evaluating evidence from scientific investigations.

These students were selected from a total of 104 students (including 50 girls) because they made a particular misconception prediction about an object's movement in a conceptual question. We purposefully selected these students to prevent one's initial domain theories from influencing the reasoning about evidence. This question showed a scenario in which a wooden block was moving on a frictionless horizontal table. The participants were told that a student was initially pushing the block in the same direction of its movement and then released it. They were asked to predict how the block would move after release by choosing one of six given options.

Materials and procedure

These selected participants worked with the researcher individually in a single session consisting of three parts: a) initial reasoning about evidence sufficiency, b) evaluating inappropriate responses to this reasoning and c) re-evaluating the inappropriate responses to this reasoning against the provided informational text that conveyed the scientific explanation.

All materials shown to the participants were in simplified Chinese. Audio recordings of all materials were made to facilitate the participants' comprehension of the materials in case some of the participants had difficulty reading the texts by themselves. The participants read these materials while listening to the audio recordings. The materials were translated into English by the first author.

Initial reasoning about evidence sufficiency

Each individual participant completed a written reasoning task on reasoning about scientific evidence. The task was adapted from studies investigating people's responses to anomalous data (Chinn & Brewer, 1998; Mason, 2000). In this task, participants were presented with a scientific prediction of the object's movement and an investigation to test this prediction. They were asked to evaluate the sufficiency of evidence from this investigation to evaluate the scientific prediction.

Scientific prediction. The participants were told that a hypothetical student answered the same conceptual question as they did and chose *Option D. Always move constantly*. This option was correct according to Newton's first law and was referred to as the *scientific prediction*.

Description of an investigation to test the scientific prediction. The participants read a brief description of the experiment to test the previous prediction. Several key design details of the experiment were described. First, the experiment was conducted in the same condition as the experiment in the conceptual question, that is, any friction and resistance could be ignored. Second, the speeds of the block were measured in 0.1-second intervals for a total duration of 2 seconds and that two trials were conducted. Third, the experimental equipment and instrument were operating well during the experiment.

Data obtained in the investigation. The participants read the data obtained in the experiment, as shown in Figure 1. The data were presented in a chart that showed the speeds over time. In both trials, the speed values remained roughly constant with a variation of around 1% over time. Taking the experimental errors into account, the data from both trials suggested that the object moved at a constant speed.

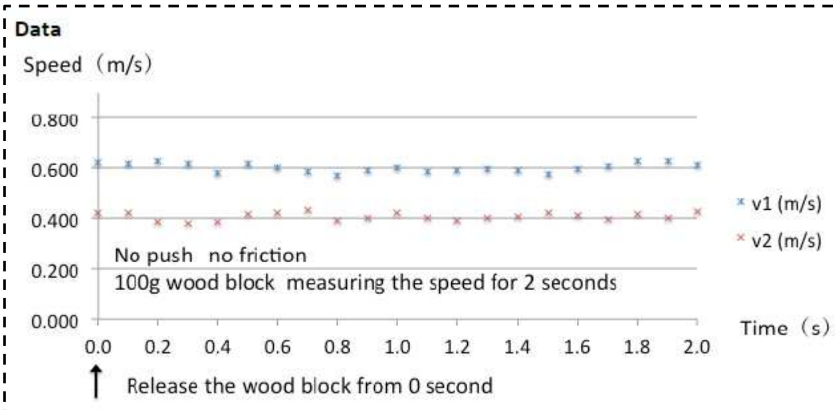

Figure 1. Data Presented in the Reasoning Task.

The participants were asked to rate the extent to which they thought the data were sufficient for evaluating the initial prediction of the movement on a 5-point scale and to explain their ratings.

Evaluating inappropriate responses of reasoning about evidence

The participants were then presented with three responses to reasoning about the sufficiency of that evidence. These responses involved using the particular inappropriate strategies for evaluating evidence, which were referred to as inappropriate responses. The participants were asked to rate the extent to which they agreed with each response and to give explanations for their ratings.

The inappropriate responses to reasoning about evidence were modified from those identified in a previous study of the authors. Three hypothetical students – A, B and C – were created to deliver these responses to participants. *Student A's response* was "I think after the student let it go, because the force keeping the wood block moving disappeared, so the block would slow down and finally stop." Student A mistakenly predicted that the block would slow down after release. *Student B's response* was "I think the speed would decrease. Two seconds is too short to see the speed decrease. We surely can see the speed decrease after the two seconds." Student B predicted that the block would slow down and considered that the duration for which the speed was measured was too short to observe the block's slowing down. *Student C's response* was "I see from the data that the speed of the blocks moves ups and downs, it is sometimes fast, sometimes slow. This is different from Tom's choice." Student C mistakenly interpreted the data as suggesting that the speed was always changing and was thus inconsistent with the scientific prediction.

Each response involved making a particular *incorrect* prediction of the movement. Student A and Student B's responses made the misconception prediction (i.e., the block would slow down). Student C's response made the claim of the data misinterpretation (i.e., the speed would be always changing).

Re-evaluating inappropriate responses against the scientific explanation

Each participant was then presented with an informational text. The informational text conveyed the scientific explanation for the scientific prediction with Galileo's thought experiment. Galileo observed that objects moved farther on smoother surfaces. The inference from this observation was that if the surface were extremely smooth and no friction was present, objects would never stop and always move at a constant speed. This informational text was intended to make the participants consider Student A, B and C's responses as *inappropriate* in terms of the claim about the block's movement.

When re-evaluating these inappropriate responses, each participant was asked to orally explain what they thought of each inappropriate response while referring to the informational text. The participants' verbal responses to reasoning about the responses to the informational text were audio recorded.

Data coding and analysis

The audio recordings of the participants' verbal responses were transcribed verbatim. The transcripts were coded to determine which participants considered the inappropriate responses as incorrect, or remained uncertain whether the responses were correct. The participants' judgments of the inappropriate responses were easily coded because they were explicitly asked to indicate their judgments when they were re-evaluating those responses. Thus it was not necessary to determine the inter-rater reliability of the coding.

We first calculated the frequencies and proportions for the participants' judgments of each inappropriate response. The transcripts of the participants who did not consider the inappropriate responses as inadequate were selected. These selected transcripts were further analysed qualitatively to identify the categories of reasons that prevented them from recognising the inappropriate response as inadequate.

Results

Table 1 shows the results of analysing participants' transcripts when they evaluated the inappropriate responses against the scientific prediction and explanation that contradicted the responses. Of all 36 participants, 15 (41.67%) did not consider Student A's response as incorrect; 11 (30.56%) did not consider Student B's response as incorrect; 17 (47.22%) did not consider Student C's response as incorrect. These participants agreed with this response or remained uncertain whether the response was correct.

Table 1: Participants' Judgments of the Inappropriate Responses against the Scientific Explanation

Inappropriate Responses	Judgment of the inappropriate responses		
	Consider the response as incorrect	Not consider the response as incorrect	Total
Student A's response	21 (58.33%)	15 (41.67%)	36 (100.00%)
Student B's response	25 (69.44%)	11 (30.56%)	36 (100.00%)
Student C's response	19 (52.78%)	17 (47.22%)	36 (100.00%)

Analysis of the transcripts of these participants' responses to the informational text found several categories of reasons for not considering the inappropriate response as inadequate.

Keeping the conflict between claims unresolved

Recall that each inappropriate response involved making a particular incorrect prediction of the movement, which contradicted the scientific prediction in the informational text. To judge the adequacy of the inappropriate response, the participants had to recognise the conflict between the competing predictions in the inappropriate responses and the informational text, and to attempt to resolve this conflict.

However, analyses found that participants kept the conflict unresolved. Specifically, three reasons for why they failed to do were identified: the participants 1) made no attempt made to resolve the conflict, 2) attempted to use data to resolve the conflict, but misinterpret the data and not attempt to use the scientific explanation to resolve the conflict; and 3) requested alternative sources to evidence and explanations requested to resolve the conflict. Due to space limitations, this paper only discusses the second theme; the other themes will be discussed at the conference.

Attempt to use data to resolve the conflict, but misinterpret the data and make no attempt to use the scientific explanation to resolve the conflict

The following excerpt demonstrates that the participant recognised the conflict between the claim of data misinterpretation and the scientific prediction and attempted to resolve this conflict by referring to the data. However, the participant ultimately did not resolve the conflict because he misinterpreted the data and did not further rely on the scientific explanation for that evidence to resolve the conflict. The participant was evaluating Student C's response against the informational text. Recall that Student C mistakenly interpreted the data as suggesting that the speed was always changing.

Researcher:	What do you think of Student C's response according to the informational text?
Participant #12:	Based on the text, Student C is definitely wrong. The text says the speed of the block will not change but continue to move forever, but Student C says the speed is sometimes fast, sometimes slow.

Researcher:	Sometimes fast, sometimes slow.
Participant #12:	I think that Student C is describing the data, but what the scientist says is different from what the data describe.
Researcher:	Oh.
Participant #12:	So is the scientist wrong, or are the data wrong?
Researcher:	You want to make a judgment?
Participant #12:	If I look at the data according to the scientist's view in the text, then the data show ups and downs, ups and downs in the two trials.
Researcher:	Oh.
Participant #12:	The text says the speed is always constant, which is different from the data. Then they are different.
Researcher:	Well, you think they are different.
Participant #12:	Yes.

This participant recognised the conflict between the informational text (i.e., the scientific prediction) and the misinterpretation of the data in Student C's response. The participant referred to the data from the investigation when he recognised the conflict and examined the consistency of the data with the competing predictions of the movement. The participant correctly used the empirical data to judge the conflicting predictions of the movement. It appeared that the participant would resolve the conflict and (mistakenly) judge Student C's response as correct because he (mistakenly) considered that Student C's response fit the data. However, the participant could not determine whether the scientist's prediction or the data from the investigation were correct. Moreover, the participant did not refer to the scientific explanation for the evidence to further consider the conflict, but rather chose to keep the conflict unresolved.

Doubting the validity of the inference from the thought experiment

Recall that the informational text presented the scientific prediction of the movement as the inference from Galileo's thought experiment. The following excerpt demonstrates that when the participant doubted the validity of the inference from the thought experiment, he did not accept the scientific prediction from the thought experiment and thus could not consider the inappropriate responses, including the misconception prediction, as inadequate. The participant was evaluating Student A's response against the informational text. Recall that Student A mistakenly predicted that the block would slow down after release.

Researcher:	According to the informational text, what do you think of Student A's response?
Participant #17:	Well, according to this text, I think… Well, I still think I am not sure.
Researcher:	Can you say it more specifically?
Participant #17:	Student A says the force keeping the block moving has already disappeared, so the speed slows down. But the scientist here says that the less the friction is, the farther it moves, indicating that it is the friction that makes the block slow down. And then there is a collision between the two.
Researcher:	Oh.
Participant #17:	I think the scientist proves what he is saying using four experiments. But he is only inferring from the four experiments. Something inferred could have errors. He is saying that the block is moving at a constant speed forever.
Researcher:	And then?
Participant #17:	My own thinking is that perhaps the movement gradually slows down after not 1 year, not 2 years, but hundreds of years, thousands of years. I am not sure about what the scientist is saying, so I am not sure.
Researcher:	Well, you think he is inferring the movement?
Participant #17:	Yes, he is inferring the movement, but he directly says that based on these experiments the block moves at a constant speed, and judges its movement after thousands of years, tens of thousands of years, billions of years. But we do not

have real data to prove that.

This participant recognised the conflict between the prediction in Student A's response and the scientific prediction in the informational text. He discounted the validity of the inference from the thought experiment and considered the inference from the thought experiment did not lead to a certain judgment about the movement after a long time. The participant suggested physical experiments data ("real data" in his terms) were necessary to conclude the block's movement for a long duration.

Mistakenly assessing the plausibility of claims about the movement

Evaluating the inappropriate responses of reasoning about the evidence against the informational text involved evaluating claims about the movement, including the scientific prediction, misconception prediction and data misinterpretation. To judge the adequacy of the responses, the participants had to judge the scientific explanation as more plausible than the claim of the data misinterpretation and the misconception prediction.

However, the analysis found that the participants mistakenly assessed the plausibility of claims about the movement. Three reasons for why participants did not consider the inappropriate responses as inadequate were identified: the students 1) considered the claim of the misinterpretation of the data as more plausible than the scientific prediction, 2) considered the scientific prediction as implausible and 3) rendered the claim of data misinterpretation plausible. We discussed the third theme here.

Rendering the claim of data misinterpretation as plausible

The following excerpt demonstrates that when the students encountered anomalous data that included unexpected variability, they invented explanations to account for the variability to render the pattern of the data as plausible. As a result, the students agreed with the claim of the data misinterpretation and thus hindered the development of the strategy for reasoning about the evidence. The participant was evaluating Student C's response against the informational text. Recall that Student C mistakenly interpreted the data as suggesting that the speed was always changing and was thus inconsistent with the scientific prediction.

Researcher:	What do you think, according to the informational text, of Student C's response?
Participant #18:	Student C's response is a bit wrong.
Researcher:	Oh.
Participant #18:	If the block were on an extremely smooth table surface, then its speed would be very even. A rough table surface could cause the friction to be uneven, and would lead to some difference in the speed.
Researcher:	What do you mean by "uneven"?
Participant #18:	There are some rough places, there are some bumps that could cause the difference in the speed.
Researcher:	Oh. It is said that we considered there was no friction.
Participant #18:	No friction, but the inertia would result in some small changes.
Researcher:	What do you mean by "small changes"?
Participant #18:	Although the block is released, its speed will have some vibration, and although the trend is decreasing, there may be some changes in the beginning, and gradually the vibration could become larger and larger.
Researcher:	Oh, you think…
Participant #18:	The inertia is decreasing, but the decrease could be uneven.
Researcher:	Oh.
Participant #18:	The decrease could be slow at first and then fast, so perhaps Student C is correct.

This excerpt demonstrates that this participant considered the data misinterpretation as plausible by proposing an explanation to account for the always-changing speed as suggested by the misinterpretation. This participant actually seemed to appeal to the data to make the claim about the movement of the block. When the participant saw the data misinterpretation in Student C's response, he attempted to explain it by noting that the speed would change from time to time.

Discussion

Factors influencing reasoning about evidence

The above findings revealed three factors influencing strategy development: 1) attempt and competence to resolve conflicts between competing claims, 2) epistemic understanding of thought experiments as a source of scientific knowledge and 3) assessment of relative plausibility of the scientific explanation to misconceptions.

Attempt and competence to resolve conflicts between competing claims

We found that some participants recognised the conflict between the predictions of the movement as indicated in the inappropriate response and the scientific prediction, yet kept this conflict unresolved. This indicates that the attempt to resolve this conflict is necessary for students to judge the inappropriate responses as inadequate and thus essential for developing the strategy for this reasoning. Even when students attempt to resolve this conflict using the empirical data, they may fail to do so because they may misinterpret the data. The competence involved in interpreting data and the attempt to use available explanations as a source for evaluating competing claims are essential for resolving conflicts and are thus important for the developing a strategy for reasoning about evidence.

In addition, students may fail to resolve that conflict when they assume the existence of alternative knowledge sources to empirical data and explanations. Recognising the role of empirical evidence and the explanations for that evidence and claims is important for resolving conflicts between competing claims of the domain, and thus is important for the development of a strategy for reasoning about evidence.

Epistemic understanding of thought experiments as a source of scientific knowledge

We found that some participants doubted the validity of the inference from the thought experiment. They did not accept the scientific prediction from the thought experiment and thus could not consider the inappropriate responses as inadequate. This indicates that when asked to evaluate the inappropriate responses to reasoning about evidence, students' beliefs about thought experiments as a source of scientific knowledge may affect their judgment of the responses in the face of the scientific prediction based on a thought experiment, and thus may influence the development of a strategy for this reasoning.

This finding adds to the literature on students' epistemic status of sources of justification for knowledge claims in science. Sandoval and Çam (2011) investigated primary students' epistemic status of sources of justification for knowledge claims and found that students appealed to empirical data as their first priority to justify a causal claim over plausible explanations. Little is understood about secondary students' epistemic status in terms of inferences from thought experiments and empirical data from physical experiments. The findings of this study suggest that secondary students appeal to empirical data as their first priority to evaluate claims of movement over thought experiments.

Assessment of the relative plausibility of the scientific explanation to misconceptions

We found some participants did not consider the inappropriate responses as inadequate due to the plausibility of the competing claims about the movement, including the scientific prediction, the misconception prediction and the claim of the data misinterpretation. This indicates the plausibility of the scientific prediction to students may affect their judgment of inappropriate responses to reasoning about evidence and thus influence the development of this reasoning strategy. This finding also indicates that when students encounter anomalous data that include unexpected variability, they may invent explanations that account for this variability to render the pattern of the data as plausible. As a result, students agree with the data misinterpretation, which hinders the development of a strategy for reasoning about evidence.

The research on conceptual change has long contended that the new scientifically accurate understanding needs to be judged as more plausible than the existing misconceptions for conceptual change to occur (Lombardi, Sinatra, & Nussbaum, 2013). The findings of this study suggest that the plausibility of the scientific prediction influences the ability of scientific prediction and explanations to foster changes in students' misconceptions.

Implications for instruction

The findings suggest to promote reasoning about scientific evidence, students need an enhanced epistemic understanding of scientific knowledge and a conceptual understanding of particular scientific domains. First, science teachers should make the scientific explanation available and plausible to students to promote their reasoning about evidence. As students evaluate the evidence, teachers could ask them to compare the scientific prediction and explanation and their misconceptions of the domain. When students recognise the conflicts between competing claims about the particular domain, teachers should prompt them to resolve the conflicts by referring to the evidence and to assess the plausibility of the competing claims.

Second, science teachers explicitly teach the epistemic understanding of scientific knowledge. Teachers must help students reflect on the roles of thought experiments in developing scientific knowledge and the relationship between thought experiments and empirical evidence. This could be useful for promoting students' acceptance of scientific claims that are drawn from thought experiments.

Future research

Future research could investigate whether and how these factors influence the development of reasoning about evidence. For example, in terms of the epistemic status of sources of justification (Sandoval & Çam, 2011), future research could investigate how students view thought experiments as a justification for knowledge claims and the priority they place on this justification compared with other justifications such as empirical data and scientific explanations. Future research could also design an experiment to test whether an enhanced epistemic understanding of the role of thought experiments in developing scientific knowledge brings about positive changes in students' reasoning about evidence.

Conclusion

This study explored potential factors that accounted for the development of reasoning during the evaluation of evidence. Specifically, it sought to identify the factors that could hinder changes in students' views on inappropriate strategies in the presence of a scientific explanation.

The results suggest that the attempt and competence to resolve conflicts between competing claims, the plausibility of the scientific prediction and explanation and the epistemic understanding of thought experiments as a source of scientific knowledge influenced the role of the scientific explanation in changing students' reasoning about evidence. The findings of this study thus contribute to the literature related to the development of reasoning about scientific evidence. We recommend that in the teaching of reasoning about evidence should make scientific explanation available and plausible to students, and address the role of thought experiments in developing scientific knowledge.

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