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Developing knower legitimation among disadvantaged learners during a science fair project planning intervention

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Abstract

Science fair projects require knowledge-building (knower legitimation), whereas school science focuses on knowledge reproduction (knowledge legitimation), particularly in disadvantaged contexts. This mixed-methods case study investigates the rate, success, and retarding factors relevant to knowledge-knower legitimation within a 6-hour science fair project planning intervention for grade 9 South African learners from disadvantaged backgrounds. The 756 questions written by 86 participants were categorized according to knowledge-knower legitimation, logic, and comprehensibility for four points across the intervention. Additionally, the teacher-researcher's reflective notes were analyzed inductively. Some knower legitimation was adopted, but incomprehensibility, illogicality, superficial compliance to the scaffolding templates, and resilience of knowledge legitimation dominated. Limited knowledge of science content and practical procedures retarded outcome attainment. A qualifying pre-competition with a knowledge focus, followed by interventions to convert these according to a relatively elite focus, is argued for. The study explicates crucial but generally hidden aspects of inquiry.

Keywords: epistemology, Expo for Young Scientists, inquiry learning and teaching, legitimation code theory, science education, science fair project planning, science content knowledge

INTRODUCTION

Scientific inquiry develops higher-order thinking skills (MacRitchie, 2018), mastery goal orientation, which is known to support conceptual learning and achievement (Mupira & Ramnarain, 2018), as well as interest and motivation to engage in science (Osborne, 2014). Science fairs, such as the South African Expo for Young Scientists (EYS) competition, can effectively promote inquiry (Ramnarain, 2020), provided learners receive appropriate support (Delisi et al., 2020). Socio-economically disadvantaged learners tend to receive little content-based support for such engagement at home (Bowen & Stelmach, 2020) or school (Delisi et al., 2020), but university-based out-of-school science fair interventions have reported some success in these contexts (Ngcoza et al., 2016; Stott, 2017; Stott & Duvenhage, 2023), particularly for higher achievers (Stott, 2019). Additional success has been reported by Gaigher et al. (2022) in a rare case of a low-quintile school (i.e., serving a disadvantaged community), which explicitly teaches learners how to produce an EYS project. These learners were found to understand scientific inquiry considerably better than learners from a more typical South African low-quintile school, as reported by Penn and Ramnarain (2022).

Drawing from such success stories, the university-based out-of-school intervention for higher achieving disadvantaged learners that this study investigated employed explicit instruction in inquiry within the context of producing an EYS project. The study sought to add to the knowledge base a greater understanding of what to expect during the project's planning phase and, therefore, how to appropriately support this. This is needed since this phase is under-supported and under-researched in such contexts (Naidoo, 2021; Ngcoza et al., 2016). Successful execution of this phase requires learners to undergo an epistemological shift from a consumer to a creator of knowledge. In the language of legitimation code theory (LCT) (Maton & Chen, 2019), as explained below, learners are required to adopt a knower specialization code despite their prior

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Contribution to the literature

- This study exposes the successes and difficulties of cultivating knower legitimation among socioeconomically disadvantaged learners.
- This is important to guide context-appropriate intervention implementation.
- Specific suggestions for such interventions are provided.

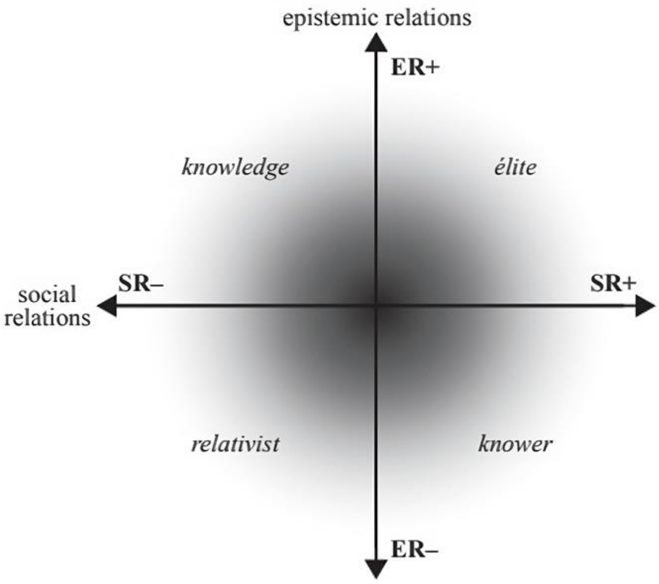


Figure 1. The specialization plane (Maton, 2013, p. 30)

experiences rather having legitimized a knowledge code.

To this end, this research was guided by the general question: What can be expected regarding the rate, success, and process of development of knower legitimation among higher achieving socioeconomically disadvantaged South African learners attending a science fair project planning intervention? To answer this question, the following sub-questions were posed, referring specifically to the intervention reported in this study:

(1) What were the characteristics of the learners' questions across the intervention?

(2) What factors retarded knower legitimation?

THEORETICAL FRAMEWORK

LCT's specialization dimension refers to epistemic relations (ER) and social relations (SR) to describe the kinds of knowledge and knowers that are considered legitimate in particular contexts (Maton & Chen, 2019). ER refers to what is counted as legitimate forms of knowledge, and SR to who can legitimately claim to be a knower. These are coded as strong (+) or weak (-) and plotted on the specialization plane (Maton, 2013) shown in **Figure 1**.

Four principal modalities emerge from the specialization plane (Maton, 2013): *knowledge codes* (ER+, SR-), which view specialized knowledge, such as canonical scientific knowledge from text books, teachers and scientists, as legitimate regardless of the knower's characteristics; *knower codes* (ER-, SR+), according to which the characteristics of the knower, such as their ability to validly manipulate and measure variables, determine their legitimacy, regardless of the extent of specialized knowledge they possess; *elite codes* (ER+, SR+), where specialized knowledge possessed by particular types of knowers is considered legitimate; *relativist codes* (ER-, SR-), where any type of knowledge is considered legitimate, regardless of its degree of specialization or the knower's characteristics. Science fairs, such as the EYS competition, operate primarily within a knower code since learners are rewarded for demonstrating inquiry-based characteristics (SR+). Although learners are also expected to study specialized knowledge, these expectations are modest (ER-) since the participants are child learners rather than adult specialists.

LITERATURE REVIEW

Globally, socioeconomic status is a strong predictor of science fair participation and success (Bowen & Stelmach, 2020; Delisi et al., 2020). South Africa has a socioeconomically defined bimodal education system, according to which the poorer 80% of learners receive considerably lower education quality than their richer counterparts (Spaull, 2013). This includes limited exposure to inquiry in both classroom teaching (Ramnarain & Hlatswayo, 2018) and in extracurricular interventions (Mupezeni & Kriek, 2018), which primarily focus on exam training (Bray, 2021). Regarding the EYS competition, this socioeconomic distinction was particularly pronounced over a decade ago. For example, Alant (2010) decried the limited participation of learners from disadvantaged backgrounds in the EYS competition, and Taylor (2011) concluded, from the counterproductive experiences of some such learners, that EYS participation was largely inappropriate for them. Within the past decade, however, the EYS organizers (Naidoo, 2021) and intervention providers, such as universities (Ngcoza et al., 2016), have tried hard to address this issue. Although this has enhanced participation by disadvantaged learners, they still tend to produce low-quality projects (Mupezeni & Kriek, 2018).

In addition to the already extensively published disadvantages associated with poverty in science fair contexts (Bowen & Stelmach, 2020; Delisi et al., 2020;

Mupezeni & Kriek, 2018) the change in epistemology towards greater legitimation of a *knower code* (Maton, 2013), required to successfully conceptualize an EYS project (Naidoo, 2021), is particularly under-supported in schools for disadvantaged learners (Ngcoza et al., 2016). This requires a shift away from the view that established science knowledge, obtained, for example, from teachers and textbooks, is the only legitimate form of knowledge. Such a knowledge-focused epistemology is strongly embraced in schools serving disadvantaged communities (Spaull, & Jansen, 2019), including in science classrooms (Ramnarain & Schuster, 2014). In contrast, inquiry, which is knower-focused, tends to be avoided (Ramnarain & Hlatswayo, 2018), with the term often being understood to refer to confirmatory practical work, with even this rarely being performed (Kibirige et al., 2022). There is even evidence for the prevalence of a relativist code in such contexts. For example, the third international mathematics and science study revealed a higher belief in luck than in hard work among South African grade 8 learners (Taylor, 2011). Consistent with such a relativist view, Taylor (2011) and Mupezeni and Kriek (2018) found that disadvantaged South African learners explained their poor performance in the EYS as arising from their bad luck and judges' bias, respectively, rather than from either their extent of specialized knowledge or their characteristics as an inquiry-based knower. Furthermore, the required change in epistemology is rarely made explicit, a condition referred to as knowledge blindness (Maton & Chen, 2019).

Pedaste et al. (2015) divide inquiry into five phases: orientation, conceptualization, investigation, conclusion, and discussion. Learners' scientific reasoning quality in the orientation and conceptualization phases (collectively referred to hereafter as the planning phase) affects the quality of the other phases. The type of scientific reasoning relevant to an experimental investigation focused on in this intervention is experimental evaluation (Kind & Osborne, 2017). To successfully engage in experimental evaluation, a learner needs to legitimize a knower specialization code (Maton & Chen, 2019). They also need to apply relevant ontic (i.e., facts about relevant concepts and principles), procedural (i.e., regarding variable identification and manipulation) and epistemic (i.e., regarding hypothesis posing and testing) knowledge (Kind & Osborne, 2017) to a specific context. This may be evidenced by the production of a comprehensible, logical, and empirically testable question to focus the rest of the inquiry, therefore referred to as focus questions hereafter. A focus questions should give the chosen independent and dependent variables a logical relationship to guide empirical experimentation. Such focus questions are termed knower-focused questions hereafter and are viewed as evidence of some degree of legitimation of a knower specialization code. This contrasts with knowledge-focused questions which may be ontic (what exists) or causal (why things happen) (Kind & Osborne, 2017). These are viewed as evidence of knowledge legitimation since such questions would likely be answered by a knowledgeable source, such as books, the internet, or the teacher, rather than through the learners' empirical knowledge-building activity.

INTERVENTION

The intervention reported here comprised three sessions of two hours each with 100 grade 9 learners from low quintile schools situated in townships in Bloemfontein, South Africa. These 100 learners were divided into two groups (45 and 55) and bussed onto a university campus after school hours. The intervention aimed to teach the basic principles of designing an experimental investigation, which could eventually become an EYS project. **Table 1** summarizes the intervention classwork and homework, as well as the purpose with which the presenter-researcher explicitly approached the intervention design and implementation in terms of knowledge-knower legitimation. Further details about the intervention are provided in the findings section.

Table 1. An overview of the intervention

Session (2 hours each)	Description	Homework task	Purpose in terms of knowledge-knower legitimation
1. Brainstorming	Perform teacher-guided whole-class discussions using a know, wonder, learn, cause and effect framework for each of four practical demonstrations.	Complete a structured worksheet applying the framework discussed in class to their idea for an EYS project.	Develop the concept that a knower can manipulate a variable (cause) with possible outcomes (effects). For this to be meaningful, the knower must be guided by relevant existing specialized and shared knowledge.
2. Variables, focus questions, treatments and measurement	Teach independent, dependent, and controlled variables, focus questions, treatments, and measurement. Apply these to teacher-led whole-class discussions about practically or pictorially illustrated investigations.	Complete a semi-structured worksheet applying the framework to their idea for an EYS project.	Develop an understanding of how a knower can validly build knowledge through their experimental investigation.

Table 1 (Continued). An overview of the intervention

Session (2 hours each)	Description	Homework task	Purpose in terms of knowledge-knower legitimation
3. Wind and evaporation investigation	Perform a prescribed investigation into the effect of the amount of wind on the evaporation rate. Complete a structured research report, including variable identification, focus questions, treatments, measurements, tabulated and graphed data, and a conclusion.	Complete a semi-structured worksheet to plan the question and method for their idea for an EYS project.	Provide an overview of the inquiry process in which a knower builds knowledge through validly manipulating and measuring variables.

Table 2. Codes used in the analysis of the learners' written work

Category	Code	Indication
Epistemology	Knowledge	Ontic (relating to what is) or causal questions (relating to why things behave as they do) (i.e., requiring answering by authoritative sources)
	Knower	Epistemic (relating to knowledge-building) questions (i.e., implying manipulation and observation by learners)
Logic	Logical	Meaning is decipherable, and logic is reasonable within the context
	Illogical	Meaning is not decipherable, and/or logic is unreasonable even when contextual information is taken into consideration.
Originality	Peer copying	Identical to someone else's written answer in a manner that makes it clear copying was involved by someone
	Repeated	The identical/very similar to a question someone other than this learner discussed in the session
	Distorted	Superficial changes to a repeated question such that it no longer makes sense
	Original	Not discussed in the session/mentioned by this learner in the session

METHOD

Sample

The science and mathematics teachers at eight low-quintile schools situated in Bloemfontein townships (densely populated areas of low socioeconomic status) identified their highest achieving grade 9 learners to be included in a university-conducted extracurricular program. This aimed to stimulate higher-order thinking skills and interest in mathematics, science, and coding. The intervention investigated in this case study formed part of this program. Of the 100 learners involved in the intervention, 86 submitted their written work and written assent from themselves and consent from their parents, agreeing to their work being included anonymously in this study.

Data Collection and Analysis

Data were collected from two sources: the 756 questions the learners generated in their workbooks and six reports that the presenter-researcher wrote about the sessions. The learners' written answers were evaluated using the coding system shown in **Table 2** to answer the first research sub-question regarding the characteristics of the learners' questions over the intervention period. Shortly after starting the knowledge-knower coding process, it became clear that the questions also needed to be evaluated for comprehensibility and logic. It is known that South African learners from schools serving poor communities tend to have poor language skills, particularly in English, even when it is the language of learning and teaching (Spaull et al., 2020; Stott & Beelders, 2019), as was the case for most of the learners in this sample. To mitigate these poor language skills, context, such as pictures and other text on the page, was considered when coding the questions' comprehensibility and logic. An additional rater classified a selection (35) of the 756 questions, with an inter-rater agreement of over 80%. Furthermore, in the findings section, examples are provided to enhance transparency. The teacher-researcher's written plans, reports, and reflections, written shortly after each session, form the data used to answer the second research sub-question regarding the factors that retarded knower legitimation. This data was analyzed inductively, guided by the research questions and theoretical framework.

FINDINGS

The findings are presented below, according to their relevant research question.

Question Characteristics Across the Intervention

The first research question refers to the characteristics of the questions the learners composed across the intervention duration. To answer this, findings regarding the learners' questions' knower-knowledge focus and logic are presented for each of four points in

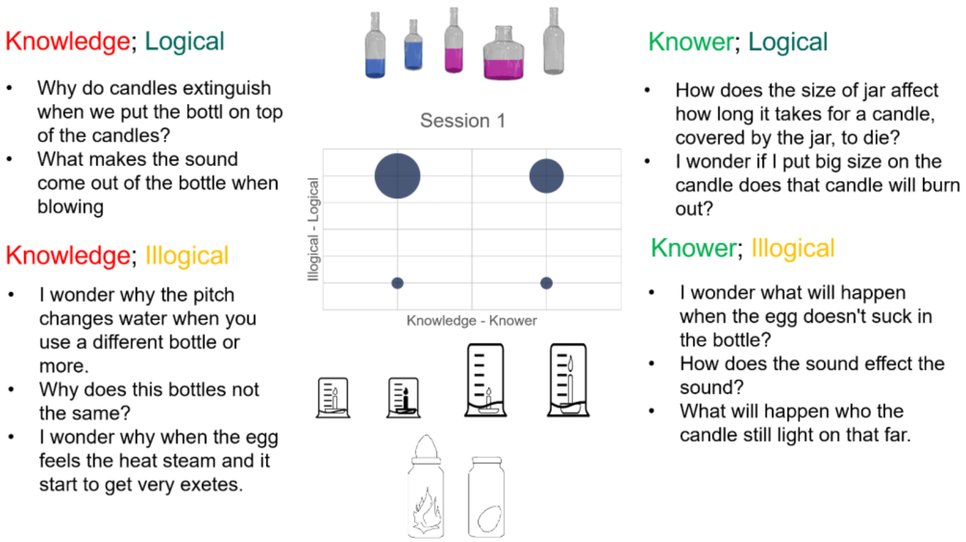
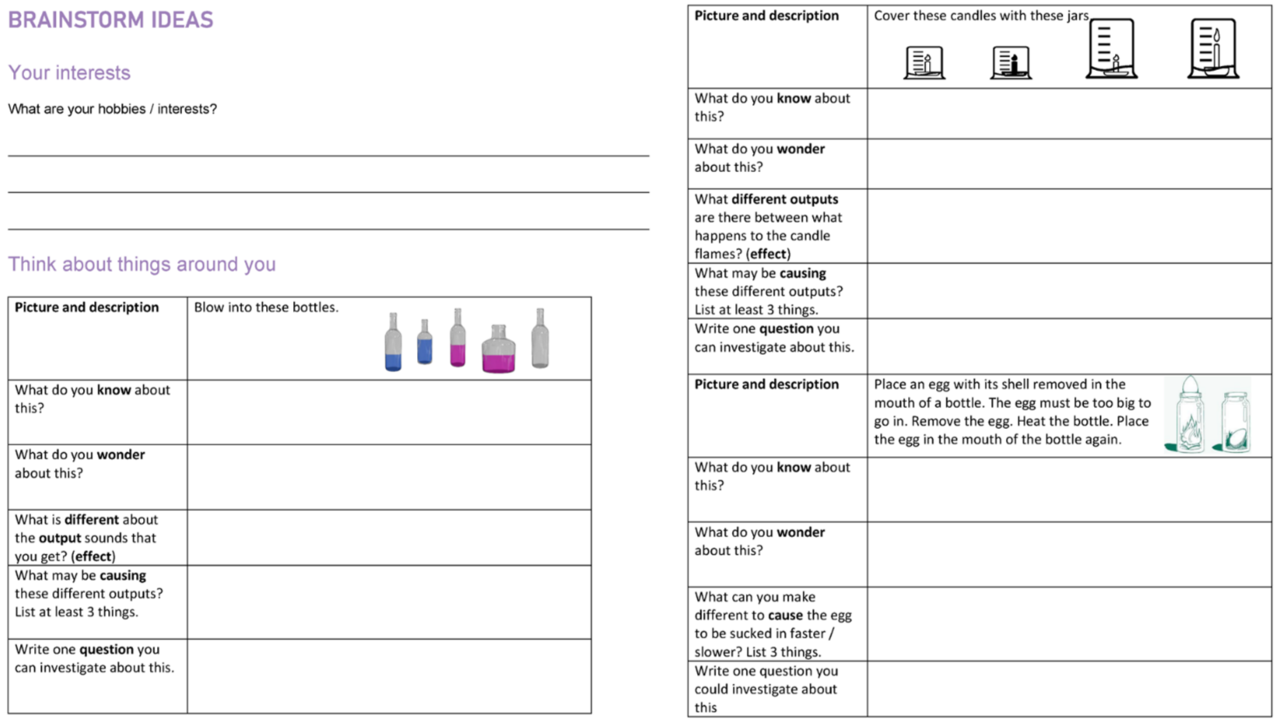


Figure 2. Findings for the first session's questions (bubble sizes represent number of questions [total number = 437]; pictures represent demonstrations which prompted the questions; & see **Figure 3** for the worksheet the learners completed) (Source: Author's own elaboration)



BRAINSTORM IDEAS

Your interests

What are your hobbies / interests?

Think about things around you

Picture and description	Blow into these bottles.
What do you **know** about this?	
What do you **wonder** about this?	
What is **different** about the **output** sounds that you get? **(effect)**	
What may be **causing** these different outputs? List at least 3 things.	
Write one **question** you can investigate about this.	

Picture and description	Cover these candles with these jars
What do you **know** about this?	
What do you **wonder** about this?	
What **different outputs** are there between what happens to the candle flames? **(effect)**	
What may be **causing** these different outputs? List at least 3 things.	
Write one **question** you can investigate about this.	
Picture and description	Place an egg with its shell removed in the mouth of a bottle. The egg must be too big to go in. Remove the egg. Heat the bottle. Place the egg in the mouth of the bottle again.
What do you **know** about this?	
What do you **wonder** about this?	
What can you make different to **cause** the egg to be sucked in faster / slower? List 3 things.	
Write one question you could investigate about this	

Figure 3. Workbook questions: Session 1 (Source: Author's own elaboration)

the intervention. This is followed by general observations regarding question comprehensibility, originality, and template usage, as well as success rate for the learners achieving the outcome of producing a basic knower-based investigation plan.

Session 1: Predominantly logical knowledge-focused questions

Figure 2 represents the 437 questions extracted from the learners' responses regarding what they wondered about and what they could investigate further regarding the three illustrated demonstrations. See the worksheet in which these instructions appear in **Figure 3** and the illustrated demonstrations, which she performed practically. This began with a knowledge-focused discussion which she had considered to be introductory and foundational to the session's focus, namely brainstorming knower-focused questions. However, the majority (n = 255 + 17) of the 437 questions generated were knowledge-focused, mainly causal, questions, with considerably fewer (147 + 18) being knower-focused. A few (17 + 18) questions were considered incomprehensible or illogical (both categorized as illogical, as defined in **Table 2**).

As suggested by the examples in **Figure 2**, the questions categorized as logical were mostly not well written, a point which was disregarded in this study if

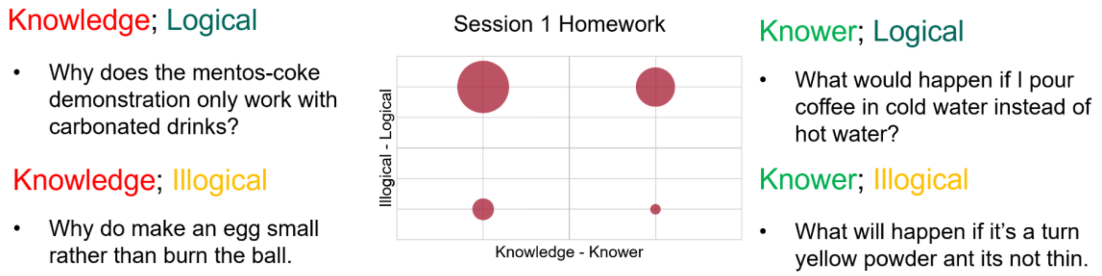
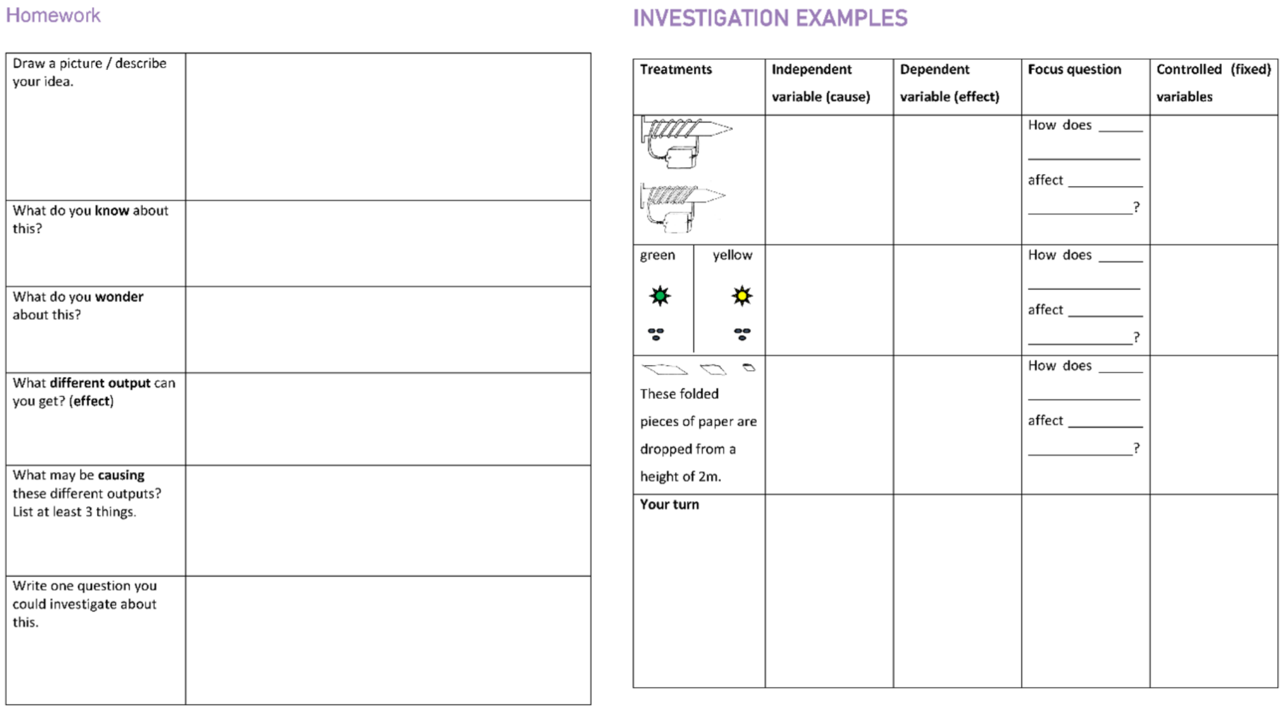


Figure 4. Findings for the first session's homework questions (bubble sizes represent number of questions [total number = 132] &see **Figure 5** for the worksheet the learners completed) (Source: Author's own elaboration)



Homework

Draw a picture / describe your idea.	
What do you **know** about this?	
What do you **wonder** about this?	
What **different output** can you get? **(effect)**	
What may be **causing** these different outputs? List at least 3 things.	
Write one question you could investigate about this.	

INVESTIGATION EXAMPLES

Treatments	Independent variable (cause)	Dependent variable (effect)	Focus question	Controlled (fixed) variables
			How does _____ affect _____?	
green yellow			How does _____ affect _____?	
These folded pieces of paper are dropped from a height of 2m.			How does _____ affect _____?	
Your turn				

Figure 5. Workbook questions: Session 1 homework (left), session 2 classwork (top right), and homework (right, final row) (Source: Author's own elaboration)

what was written was comprehensible and logical within the context of other text and images appearing on that page. A comparison of the logical and illogical examples in **Figure 2**, bearing in mind the images that appeared on the worksheet, illustrates how these criteria were applied. For example, although "I wonder if I put a big size on the candle, does that candle burn out?" is incomprehensible on its own, together with the image of variously sized jars covering candles, this question is comprehensible and logical. In contrast, even with this image, "What will happen who the candle still light on that far" is incomprehensible and "I wonder what will happen when the egg doesn't suck in the bottle?" is illogical since it is not the egg which sucks in the bottle. Even if the allowance is made that the learner intended rather to write "… when the egg is not sucked into the bottle", this provides the answer, making the question illogical. The latter example illustrates a limitation of evaluating the logic dimension based on assumed intention rather than only text since the learners' intent could be speculated as "I wonder what might cause the egg not to be sucked into the bottle?". Interviews with the learners would have reduced this limitation, but these were not possible given the researcher's limited access to the learners. A degree of transparent reporting, as allowed by space, such as providing examples of learners' answers according to how they were categorized, is provided to enable readers to judge the extent of this limitation.

Session 1 homework: predominantly logical knowledge-focused questions

Figure 4 provides a similar type of representation for the questions extracted from the session 1 homework worksheet (**Figure 5** left-hand side). The learners were prompted to apply a similar questioning style to their project idea as had been discussed in the session.

Fewer total questions (n = 132), in response to fewer prompts, were extracted, but the ratio of knowledge- to knower- focused questions showed a slight relative increase in knowledge-focused questions from the

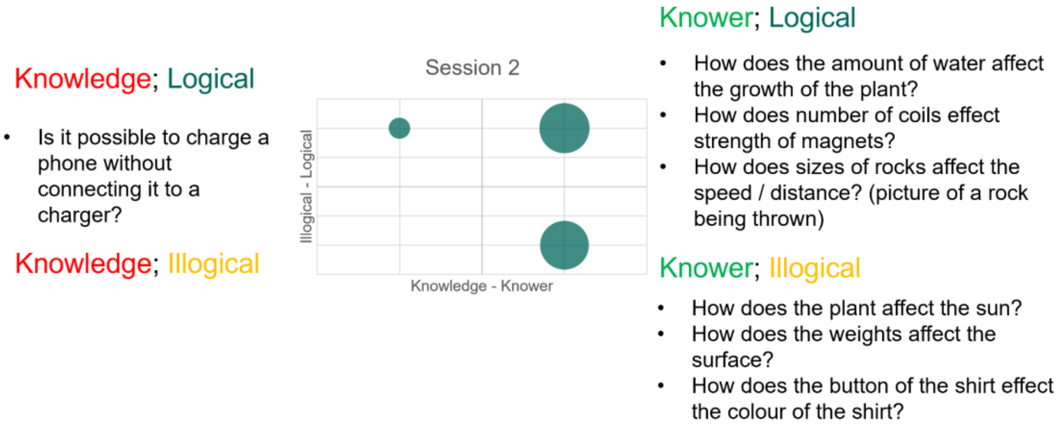


Figure 6. Findings for the second session's homework question (bubble sizes represent number of questions [total number = 81] & see **Figure 5** left hand side bottom row for the template the learners completed) (Source: Author's own elaboration)

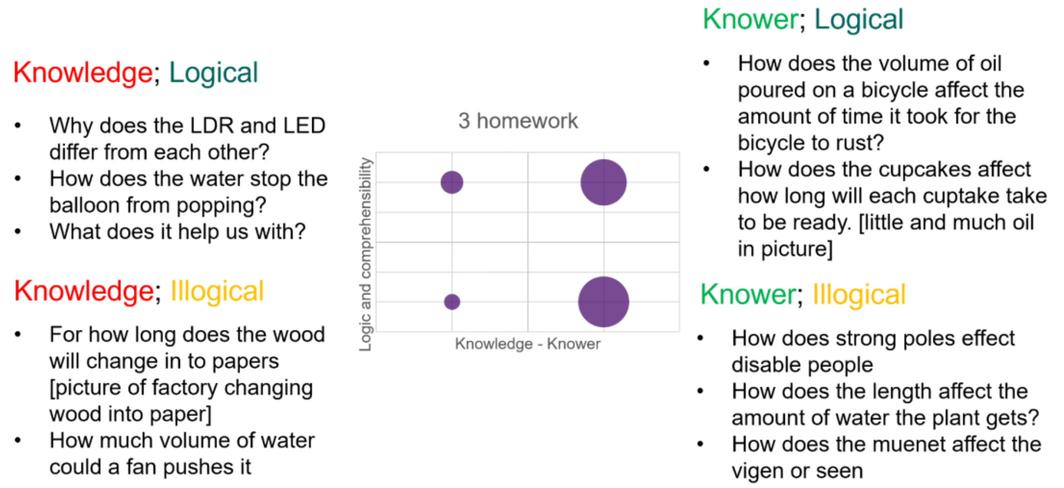


Figure 7. Findings for the final session's homework questions (bubble sizes represent number of questions [total number = 106] & see **Figure 8** for the template the learners completed) (Source: Author's own elaboration)

session (272:165 = 1.6:1) to the homework (87:45 = 1.9:1). The ratio of illogical: logical questions showed a slight rise in illogicality between the session (35:402 = 0.08:1) and the homework (16:116 = 0.1:1). The lack of teacher prompting for the homework may explain these slight deteriorations, however even with the teacher's prompting towards knower-focused questions in the session, knowledge-legitimation was clearly dominant.

Session 2: Predominantly template-induced knower-focused questions; much illogicality

During the second session, the presenter provided a framework for writing a focus question ("How does [independent variable] affect [dependent variable]?"). This was modelled with three examples (see **Figure 5** right-hand side). To create a logical knower-focused question the learners needed to slot a dependent and independent variable into the appropriate spaces in the template. Session 2's targeted learning outcomes included the ability to understand these types of variables to be able to identify them in the three provided examples as well as in the learner's own project idea. **Figure 6** represents the counts of the classification, as well as some examples of each classification group, for the focus questions the learners provided within and next to this template. Some learners chose not to use the provided template, with seven of these resulting in logical knowledge-focused questions. The remaining questions were template-imposed knower-focused questions with a considerable number (n = 36 out of 74 = 48%) being illogical.

Session 3 homework: Predominantly template-induced illogical knower-focused questions

Figure 7 represents findings from the final task, in which the learners planned their own investigation using the knower-focused template given in **Figure 8**. Again, several learners chose not to use it, with 15 of these producing knowledge-focused questions. The results show a relative rise in knower-focused questions (91 knower:15 knowledge = 6:1 in the final task vs 210:359 = 0.6:1 for the first session and its homework tasks).

Prevalence of Incomprehensibility Out of Context, Unoriginality and Superficial Distortion

Of the 212 logical questions posed within contexts where originality was encouraged (i.e., all except session 1), only 100 (47%) were both original and knower-

YOUR INVESTIGATION

1. Give the:

a) **Independent** variable (what the investigator will make different between the treatments; the **cause**):

____

b) **Dependent** variable (the outcome variable: what becomes different because of the difference between the treatments; the **effect**):

____

c) **The focus question**:
(Can often be written as "How does [independent variable] affect [dependent variable]?)

____

d) **Controlled variables** (fixed variables; variables which must be kept the same between treatments so that this will be a fair test; list all significant variables which must be controlled):

____

____

2. You must have at least 2 treatments which differ in the independent variable.

Describe and/or draw set-ups to show these 2 (or more) treatments.

- Would you like to participate in the Expo for Young Scientists competition? Yes ____ No ____
- Are you prepared to do the work required to participate in the Expo for Young Scientists competition? Yes ____ No ____

Figure 8. The final homework questions (Source: Author's own elaboration)

focused questions, according to the definitions given in **Table 2**. These tended to be incomprehensible out of context (such as the picture of a moving rock in **Figure 6** and varying amounts of oil in **Figure 7**). Another 77 were original but knowledge-focused questions. The remainder were peer-copied (21), repeated from examples used in the sessions (11) or superficial distortions of examples used in the session (3). Of the 107 illogical questions, 74 were original, 7 peer-copied, and 26 were superficial distortions, particularly of the surface area vs air resistance example used in session 2 (see **Figure 5** on the right-hand side), e.g., "How does the weights affect the surface?" (**Figure 6**).

Intervention Success for Approximately 1/3 of Participants

For the final task (**Figure 8**) only 32 of the 100 learners submitted an original, logical knower-based questions with associated brief method plans, which could therefore be used as the starting point of a science fair project. Since this was an objective of the intervention, a 32% success rate can be reported. Since only 86 of the 100 learners submitted their work, this success rate should perhaps rather be reported as 37%. It was evident that the majority of the learners who failed to submit their work had not done the work, so that the actual success rate probably lies between 32% and 37% and is taken as being approximately 1/3. Besides this rate being low, the learners' heavy reliance on the provided templates, and the lenient criteria for logic and comprehensibility mean that even for this 32%: development of knower-legitimation cannot be claimed; much work would still be required to transform these learners' topics into science fair projects. Reasons for this low success rate and limited autonomy and quality in the work of even the learners labelled as successful, are discussed next, in answer to the second research question, regarding the factors which retarded development of knower-legitimation.

Retarding Factors

The teacher-researcher facilitated discussions in relation to each of the demonstrations she used. These discussions were aimed at revealing prior knowledge (knowledge focus), prompting brainstorming about variables to be manipulated (bridge between knowledge and knower focus), and converting each demonstration into an experimental investigation (knower focus). However, these discussions revealed that the learners' poor content knowledge, language skills, and

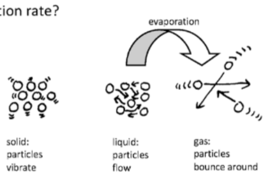
EXAMPLE: WIND AND EVAPORATION

Taken, with permission, from *Experimental Investigations* by Angela Stott

Focus question: How does amount of wind affect evaporation rate?

Background theory:

All things are made of moving particles. If they move so slowly that they just vibrate[1] at one place, they are in the solid phase. If they move a little faster, flowing over one another, they are in the liquid phase. If they bounce around quickly, they are in the gaseous phase. Changing from liquid to gas is called evaporating.



Hypothesis: Evaporation rate _______________ with increased amount of wind.

Method:

Apparatus: Water, measuring cylinders, petri-dishes

Treatments:

Place petri dishes, each containing 10ml water, at the following distances from a fan:

A: ____________________ B: ____________________

C: ____________________ D: ____________________

Outcome measurement:

Measure the ___________ of the water in each petri-dish at the start, and again at the end, of _____ hour(s). Calculate the difference in these volumes to indicate evaporation rate.

Controlled variables:

A, B, C and D all had the same:

____

____

____

[1] vibrate: move back and forth

Results: (see the appendix for the raw data table)

a) Table

Processed data: The effect of amount of wind on evaporation rate

Distance from fan (m)	Volume of water which evaporated in ____ hour(s) (ml)

b) Graph

Conclusion: ____

____

Appendix

Raw data: The effect of amount of wind on evaporation rate

	Distance from fan (m)	Initial volume of water (ml)	Final volume of water (ml)	Change in water volume (ml)
A				
B				
C				
D				

Figure 9. Session 3's workbook questions (Source: Author's own elaboration)

unfamiliarity with measurement hindered this progression. Possibly related to this hindrance, very little application of the knower-focused instruction was observed beyond that forced by the writing template and guided by fine-grained teacher prompting. These findings, gained from the qualitative analysis of the teacher-researcher's reports guided by the second research question, are illustrated below.

Poor Content Knowledge Hindered the Knower Focus

Examples of poor content knowledge exposed through teacher-prompted discussions include not knowing that air contains oxygen, that oxygen is needed for, and that carbon dioxide is produced during, combustion, and that heat causes expansion. Each of these is included in the grade 8 natural sciences curriculum, and yet only one of the four sub-groups of learners had learners who volunteered correct answers to questions about these topics. Misconceptions revealed during the discussions included that air evaporates when heated, a piece of paper gains mass when folded, and there is no gravity on the moon. General group agreement about these views, sometimes chorused out with no apparent dissent from others, suggested they are widespread. The consequence of this poor content knowledge, all of which is included in earlier grades' curricula, was that time, attention, and cognitive resources were consumed in trying to develop the content knowledge required for epistemic application, which consequently suffered relative neglect.

Poor Language Skills Hindered the Knower Focus

The hindrance that poor language skills played in developing a knower focus has been illustrated in the learners' written focus question examples. Limited scientific vocabulary was particularly found to slow progress. For example, the teacher asked how the sounds obtained differed from one another when she blew into different bottles. The learners responded, "soft and loud". The teacher used her voice to make loud and soft sounds of equal pitch and deep and high-pitched sounds of equal loudness, each time asking the learners to describe what was different between each pair of sounds. She encouraged the learners to use any language. In one of the groups, one learner used the term "pitch". The other learners' reactions suggested they had never heard this term, and the second group was unable even to suggest "deep and high" in any language.

Unfamiliarity with Measurement Hindered the Knower Focus

On the third day of the intervention, the learners conducted a hands-on investigation into the effect of the amount of wind on the evaporation rate, guided by the worksheet given in Figure 9. The various measurements that had to be made were divided amongst the learners. These were: measuring out 12 repetitions of 10 ml of water; the four treatment distances, each 1m from the fan; the treatment period; the final water volume in each container.

These activities revealed unfamiliarity with basic measurement. For example, the learners needed help to interpret the 0.1 ml increments on the measuring cylinders. Also, they displayed difficulty in identifying where 1 m, 2 m, 3 m, and 4 m positions were on a tape measure. In this session, the teacher also prompted small-group and whole-class discussions on measurement instruments and how the learners would measure the dependent variables in their own planned investigation. The following extract from the teacher-researcher's reflective report about this process further illustrates the learners' unfamiliarity with measuring instruments and how this detracted from a productive epistemic focus on experimental investigation.

> Several times, when I asked questions intended for a quick chorus just to check basic information, I was met with silence even when I required a general chorus or responses to peers rather than the more intimidating individual response to the whole class. For example, I asked what instrument we used to measure distance from the fan, and everyone was quiet. They had already seen and used it, and I had said it was a measuring tape, so I thought this question would establish a connection rather than halt the flow of instruction. Similarly, when one girl said that she would measure "the sun that the water absorbs", I rephrased, "ok, you'll measure how hot the water gets - how will you do that? - what instrument will you use?" she said she didn't know. I asked if anyone could help her and was met with silence. I asked, "What do you use to measure how hot something is?" There was still silence, so I said, "Is it a watch?" There were a few hesitant "No"s. I continued like this for a while because I thought they had surely heard about a thermometer. Eventually, one learner said, "Thermostat". I said, "Nearly. Can anyone help?" There was still no answer, so I gave the answer.
>
> Later, we discussed one of the learners' ideas to use different floor polishes. I asked what the output variable was. I clarified, "What might be different because of using different floor polishes?" Again, there was silence even when I told them to tell their neighbor. Eventually, a learner said, "Shininess". I asked how we can measure shininess, and a learner said, "We will see if it is shiny". I asked, "How will we measure different amounts of shininess?" One learner replied, "We will look at it". Another said he would rub each floor for 5 minutes, and then he would see how shiny it was. I asked him, "Ok, but how will you measure how shiny it is?" He replied that he would measure 5 minutes with a watch. I then suggested that judges could be used to give a shininess mark for each floor. It didn't seem, though, that the learners understood what I was saying, so I dramatized the process. The session felt long and labored.

Knower-Focused Instruction Was Hardly Applied Beyond the Template and Fine-Grained Prompting

The quantitative data regarding the learners' focus questions has revealed that some learners used the template to generate successful knower-focused questions. However, for many, the template seemed to encourage illogical distortion of the provided examples, and for several learners, even the template failed to elicit a knower-focused question. The qualitative data regarding the learners' verbal interactions during the sessions suggest even less internalization of the instruction about variable manipulation in a knower-focused question. The following extract is from the teacher-researcher's report about a brain-storming session in which the learners shared their ideas with one another in a speed-dating format, followed by a whole-class discussion, at the end of the second session. Note the ideas' knowledge focus:

> The learners were reluctant to volunteer, but eventually four shared their ideas. These were about making: something that holds a phone in the air to take a selfie; a perpetual motion machine with magnets; lipstick which is not dissolved by saliva; a renewable energy generator. I tried to lead each volunteer to turn their thoughts into an investigation by guiding them to apply what we had done in the session to their idea, but this was not successful.

Several factors account for the limited success observed. The extract below is taken from the teacher-researcher's report about the final session's wind and evaporation investigation. It suggests that the learners had not understood what had been taught about controlled variables in the previous session.

> I asked what variables needed to be kept the same between the different Petri dishes for a fair test. First they discussed this in their groups, and then I conducted a whole-class discussion. A girl volunteered, "amount of water". I asked, "When must the Petri dishes have the same amount of water?" I was met with silence, so I asked, "Do you think they'll have the same amount of water now, at the end of an hour of wind?" Eventually someone said they must have the same amount of water at the beginning. I asked for another controlled variable, and the next group said, "distance from the fan". I pointed out that that was one thing which could not be kept the same if we wanted to answer this focus question. I had already spent at least an hour last time explaining fair testing with examples, stressing that the independent variable must not be kept the same

> between the treatments. Then the next group answered, "amount of wind". I pointed out this was related to "distance from the fan", so it should also not be kept the same between the treatments. Four out of the eight groups indicated they had listed either of these as controlled variables.

When the teacher-researcher prompted the learners in a step-by-step (i.e., fine-grained) manner, some did evidence productive knower-focused progress. This is illustrated in the extract below from the teacher-researcher's report about the part of the final session in which the learners were meant to discuss their own investigation ideas. The teacher-researcher noticed that when she instructed them to do this in their groups, there was silence, so, in an attempt to illustrate what was required, she mentioned the problem raised by a learner in the group that had attended earlier in the week, namely that lipstick comes off too easily:

> I asked what is in lipstick. One said "coloring", and one said "oil". Then I asked, "How can we make two lipsticks different from one another?" First, there was silence, so I started off with "maybe in this one we use…." Then learners volunteered things like "fish oil" and "Vaseline". I responded, "Good, so what is our independent variable? What is different between the treatments?" Someone said, "Type of oil".
>
> After a few minutes of this kind of discussion, I again instructed the learners to discuss their own ideas in groups. After a while, I asked for volunteers to share their ideas with the class. One girl said she would investigate: How does the amount of concentrated juice affect the color of the juice? I asked her if she could be more specific than "amount", and she replied "volume". I asked how she would measure the color of the juice, and she said she would see it. I said actually she is interested in the darkness of the color, and she could use a piece of paper with an X drawn on it, look through the juice to the X behind it, and then move the paper until the X can just no longer be seen, and then measure the distance between the juice and that position. The learners did not seem to listen, though. Later, someone suggested that a way to measure the color was to sort the juices from darkest to lightest. Another girl said she would investigate how the sun is attracted to water. The way she spoke confused a number of ideas and was vague. I asked her what she would make different between her treatments, and then she became clearer. She said, "the amount of water". I asked her to be more specific, and she said "volume" and that her independent variable was the volume of water.

Although it generally appeared that fine-grained prompting such as this was needed for the learners to make progress, there is one piece of evidence in the teacher-researcher's reports which suggests this was not always the case:

> One boy who had never volunteered an answer before managed to give a correct answer without me prompting him individually. He said his independent variable is the volume of Coke and his dependent variable is the time taken for the Coke to erupt when two Mentos are placed in it, so his focus question is "How does the volume of coke into which Mentos are dropped affect the time it takes to erupt?"

DISCUSSION

In disadvantaged contexts interventions often yield little if any measurable success (Bayat et al., 2014), and therefore the attainment of the intervention's outcome by about a third of the sample is positive. This outcome was producing the basic plan for a logical experimental investigation within the six-hour intervention and additional homework time. However, the learners' heavy dependence on the template to do this undermines the claim that this success resulted from knower legitimation and that the learners would be able to expand on and implement these, or any other, plan with autonomy, as would be required for them to participate meaningfully in a science fair competition.

The limited progress made towards knower legitimation is consistent with literature on the deep entrenchment of a revelatory intergenerational culture of knowledge transmission, which permeates home and school life within most developing world societies (Guthrie, 2021), as well as the general avoidance of inquiry by teachers in such contexts (Ramnarain & Hlatswayo, 2018) partly because they themselves may not legitimize an epistemic, knower-focused pedagogical orientation (Ramnarain & Schuster, 2014).

The limited progress made towards autonomy in inquiry is also consistent with available literature. Academic autonomy is dependent on the ability to read with a high degree of fluency and comprehension (Lesiak & Bradley-Johnson, 1983), which is known to be strongly related to extent of subject matter knowledge (SMK) (Smith et al., 2021). Reading skills are generally very poor among learners from disadvantaged SA schools (Spaull & Pretorius, 2019), even among those who are relatively academically strong, regarding reading sciences texts (Stott & Beelders, 2019). This explains why Stott and Beelders (2019) found that only the small percentage (32%) of their sample of higher achieving learners from South African township schools who were able to read above the frustration level benefited from extracurricular university-based science interventions aimed at promoting higher order thinking skills, such as guided problem-solving and inquiry. It is interesting that the approximate 1/3 success rate in this study matches Stott and Beelders's (2019) 32% finding. Both drew the approximately 10 highest achievers from about 100 total grade 9 learners per school, making the success percentage per population about 3%. This may mean that about 3% of disadvantaged South African learners are able to read science texts above the frustration level and consequently may be able to display the autonomy required for a science fair project following an appropriate intervention.

The findings also confirmed what is known about the low SMK of disadvantaged learners (Reddy et al., 2016), even those who achieve high marks relative to other learners in their schools (Stott & Duvenhage, 2023), and even those who win medals in a science fair competition (Mupezeni & Kriek, 2018). In addition, the findings illustrate that successful knower legitimation, including knower-focused question generation, depends on having a well-developed knowledge base. From this the argument is made, below, that relative to the context, an elite legitimation code may be required for successful participation by learners from disadvantage in science fairs.

Furthermore, these findings support arguments, such as those made by Emden (2021) that the cognitive load experienced by high school learners engaging in inquiry justifies explicit instruction in the *scientific method*, rather than its avoidance in the interests of promoting a more expansive view of the nature of science (Ioannidou & Erduran, 2021). This is particularly the case for disadvantaged learners (Stott, 2018) where it is clearly unreasonable to advocate, as Kind and Osborne (2017) do, for a focus on six types of scientific reasoning, rather than only the two which the *scientific method* develops. The intervention investigated in this study only attempted to develop one of these types of reasoning, experimental evaluation, with the limited success obtained involving much effort, frustration, and difficulty from both the teacher and the learners. Clearly engaging in scientific reasoning is complex and cognitively taxing. Some of this complexity is explained by Kind and Osborne's (2017) reference to the required application of ontic, procedural, and epistemic knowledge related to each kind of reasoning. For example, they list knowledge of measuring instruments as ontic knowledge necessary to engage in experimental evaluation. This study confirmed this necessity, as well as illustrating how limited such knowledge is amongst even higher achieving disadvantaged learners. But in addition to the various kinds of knowledge unique to the targeted type of scientific reasoning, this study revealed the necessity of learners possessing ontic knowledge of the topic under investigation (SMK) before they can engage in scientific reasoning.

This may be seen as contradicting the view that a "knowledge-lean" (Kind & Osborne, 2017, p. 21) approach can be taken to develop scientific reasoning (Klahr & Dunbar, 1988). This view is related to that given earlier, that knower, as opposed to elite, legitimation (see **Figure 1**) is needed to produce an experimental investigation for a science fair. Such a contradiction is consistent with views that scientific reasoning can only be developed domain-dependently (Willingham, 2008) and therefore a knowledge-based curriculum into which reasoning skills are embedded is more successful than one which stresses reasoning over knowledge (Young, 2013). Alternatively, it may be argued that the SMK required to make progress in engaging in scientific reasoning, developing knower legitimation, and being able to produce a science fair project successfully, is indeed low, justifying a *knowledge-lean* approach and an aim for knower-legitimation, but the extremely low science knowledge levels of disadvantaged learners is even lower than these requirements. Indeed, the missing SMK which halted progress in this study's findings, does seem to be basic and covered by lower grades' curriculum requirements, perhaps supporting this view. However, such a view seems unhelpful in making progress in this context. Perhaps more helpful is the view that for the context, relatively high knowledge levels are needed for the development of scientific reasoning skills needed to engage in an experimental investigation for a science fair. Within LCT, this translates to requiring learners to possess a relatively elite legitimation code, i.e., having both a high regard for, and possession of high levels of, knowledge relative to their peers, as well as understanding that they have epistemic agency to create knowledge through inquiry. In interpreting what is intended by the term *relatively elite*, the reader should remember that the learners in this study were the highest achieving learners in their schools, which were situated in South Africa's generally highest achieving province.

In other words, it appears that it is only feasible for those learners who come to an intervention with very high levels of scientific SMK, relative to the context, to develop the epistemic understanding required for participating in a science fair. Such a view confines participation in science fairs to very few learners (possibly about 3% of the population) within disadvantaged contexts. The need for such confinement can be understood in terms of cognitive load theory. It is highly cognitively taxing to engage in scientific reasoning (Zacharia et al., 2015). Consequently, even in more privileged schools, the ability to autonomously design an investigation requires extensive guidance through various stages of varied levels of adult support (Ramnarain & Hobden, 2015). Learners at these more privileged schools are known to have significantly better SMK (Reddy et al., 2016) and reading ability (Spaull & Pretorius, 2019), as well as experiencing significantly more exposure to science practical work (Kibirige et al., 2022) and an inquiry orientation (Ramnarain & Schuster,

2014) than learners from disadvantaged backgrounds. Each of these factors obviously further enhance the cognitive load which disadvantaged learners experience when participating in a science fair. This explains the limited success reported in this study's quantitative findings, as well as the frustration and slow progress evident in the qualitative findings.

Unfortunately, the focus, in disadvantaged contexts, tends to be on pass rates rather than on pass quality (Stott et al., 2015), resulting in relative neglect of the higher achieving "elite" learners who are unlikely to fail school exams and are therefore not considered to be at risk. Additionally, extracurricular interventions such as the one investigated in this study, are rare in disadvantaged contexts, since curricular exam-training is rather needed to raise pass rates (Okitowamba et al., 2018). This situation means that the higher achieving learners who could benefit from extracurricular activities (Stott & Duvenhage, 2023) such as inquiry and science fair engagement (Stott, 2019) and therefore could reduce the socio-economically based disparities evidenced at such fairs (Bowen & Stelmach, 2020), and could benefit from their multiple benefits (Ramnarain, 2020), tend not to be given the necessary help to do this. Denying the reality that such interventions require selection of a small elite for success further exacerbates this situation since without such selection interventions prove to be unfeasible, as this one could be seen as having been for approximately 2/3 of the participants despite having employed some ability-based selection. There is some evidence that using school science marks may be an appropriate selection method (Stott & Beelders, 2019). An alternative suggestion, which has the additional benefit of contributing to the science fair project production process, is proposed next.

Suggestions for Practice

The obstacles this and other studies have revealed to disadvantaged learners taking even only the first step towards engaging in a science fair are relevant towards understanding issues of equity in science fairs in South Africa (Alant, 2010; Mupezeni & Kriek, 2018; Naidoo, 2021; Ngcoza et al., 2016; Taylor, 2011) and elsewhere (Bowen & Stelmach, 2020; Delisi et al., 2020). To achieve greater representation of learners of lower socio-economic status, the time- and resource-intensive requirements to make relatively little progress, and the need for selecting relatively elite learners for participation in interventions for science fair preparation, as illustrated in this study, need to be acknowledged and factored in.

The first step towards this could be in the form of a pre-science-fair competition, which requires learners to demonstrate a phenomenon practically and explain this scientifically, after which they could be guided to convert this demonstration into an experimental investigation for the science fair. This first competition would offer less cognitive load to learners since it would be situated within the more familiar knowledge code and would not require learners to attend to the procedural and epistemic knowledge required in experimental evaluation, such as identification and manipulation of dependent, independent, and controlled variables. The focus, therefore, could be on mastery of relevant SMK. Demonstration of this mastery could then filter out learners who are likely to be able to benefit from a subsequent intervention to guide learners to modify their demonstration into a variable-manipulating experimental investigation. This could be expected to be more effective than this intervention was because qualifying learners would be more familiar with the foundational SMK of their chosen topic, and therefore be more able to apply cognitive resources to the required epistemic change.

This suggested altered competition structure is consistent with those made by Schmidt and Kelter (2017) for more and smaller science fair events, based on their findings in the United States of America, that the length and complexity of projects cause stress which decreased attitudes towards science, technology, engineering, and mathematics subjects. The alteration suggested here may therefore be applicable beyond the context of disadvantaged learners and may improve the effectiveness of science fairs more broadly.

CONCLUSIONS

This research sought to explore what might be expected regarding the rate, success, and process of development of knower legitimation among higher achieving socioeconomically disadvantaged South African learners attending a science fair project planning intervention. The findings suggest that an intervention such as investigated here can be expected to help approximately a third of a sample of learners if selected as done here (therefore approximately 3% of the learner population) to generate logical knower-focused questions across three 2-hour contact sessions which includes homework. There was little evidence of internalization of knower legitimation beyond the progress ascribable to fine-grained verbal and template-constrained written prompting, and this was ascribed to the learners' poor content knowledge, language skills and unfamiliarity with measurement. These findings highlighted the need for learners to have a knowledge base which is very well developed for their context before they can be expected to benefit from a knower-focus intervention, such as this one. Since only very few disadvantaged learners possess such a knowledge base, a relative elite code may be necessary for science fair success in disadvantaged contexts. These learners should be seen as vital assets to be capitalized on in research-informed manners, for their own sakes as well as for enhancing equity and uplifting their disadvantaged communities. Unfortunately, currently such learners are rather largely neglected, as they are classified as not being at risk of lowering the examination pass rate statistics which currently incentivize many interventions in disadvantaged contexts. Further research could investigate the feasibility and efficacy of the alterations to science fairs and related interventions which have been proposed here, for disadvantaged learners and, possibly, more broadly too.

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REFERENCES

Alant, B. P. (2010). "We cross night": Some reflections on the role of the ESKOM Expo for Young Scientists as a means of accommodating disadvantaged learners into the field of science and technology. *Perspectives in Education, 28*(4), 1-10. https://www.ajol.info/index.php/pie/article/view/76938

Bayat, A., Louw, W., & Rena, R. (2014). The impact of socio-economic factors on the performance of selected high school learners in the Western Cape Province, South Africa. *Journal of Human Ecology, 45*(3), 183-196. https://doi.org/10.1080/09709274.2014.11906692

Bowen, G. M., & Stelmach, B. (2020). Parental helping with science fair projects: A case study. *Canadian Journal of Science, Mathematics and Technology Education, 20*, 342-354. https://doi.org/10.1007/s42330-020-00087-6

Bray, T. M. (2021). *Shadow education in Africa: Private supplementary tutoring and its policy implications*. Comparative Education Research Center, The University of Hong Kong. https://doi.org/10.4324/97810003317593-6

Delisi, J., Kook, J. F., Fields, E., Winfield, L., & Levy, A. J. (2020). An examination of the features of science fairs that support students' understandings of science and engineering practices. *Journal of Research in Science Teaching, 58*(4), 491-519. https://doi.org/10.1002/tea.21669

Emden, M. (2021). Reintroducing "the" scientific method to introduce scientific inquiry in schools? A cautioning plea not to throw out the baby with the bathwater. *Science & Education, 30*(5), 1037-1073. https://doi.org/10.1007/s11191-021-00235-w

Gaigher, E., Hattingh, A., Lederman, J., & Lederman, N. (2022). Understandings about scientific inquiry in a South African school prioritizing STEM. *African Journal of Research in Mathematics, Science and Technology Education, 26*(1), 13-23. https://doi.org/10.1080/18117295.2022.2056373

Guthrie, G. (2021). Foundations of classroom change in developing countries. In *Classroom change in developing countries* (Vol. 2, Issue February). Routledge. https://doi.org/10.4324/9781351130479

Ioannidou, O., & Erduran, S. (2021). Beyond hypothesis testing: Investigating the diversity of scientific methods in science teachers' understanding. *Science and Education, 30*(2), 345-364. https://doi.org/10.1007/s11191-020-00185-9

Kibirige, I., Teffo, W. L., & Singh, S. (2022). Investigating teachers' perceptions of facilitating scientific investigations. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(2), Article em2074. https://doi.org/10.29333/ejmste/11511

Kind, P., & Osborne, J. (2017). Styles of scientific reasoning: A cultural rationale for science education? *Science Education, 101*(1), 8-31. https://doi.org/10.1002/sce.21251

Klahr, D., & Dunbar, K. (1988). Dual space search during scientific reasoning. *Cognitive Science, 12*(1), 1-48. https://doi.org/10.1016/0364-0213(88)90007-9

Lesiak, J., & Bradley-Johnson, S. (1983). *Reading assessment for placement and programming*. Charles C Thomas.

MacRitchie, F. (2018). *The need for critical thinking and the scientific method*. CRC Press. https://doi.org/10.1201/9781351255875

Maton, K. (2013). *Knowledge and knowers: Towards a realist sociology of education*. Routledge. https://doi.org/10.4324/9780203885734

Maton, K., & Chen, R. T.-H. (2019). Specialization codes: Knowledge, knowers and student success. In J. R. Martin, K. Maton, & Y. J. Doran (Eds.), *Accessing academic discourse* (pp. 35-58). Routledge. https://doi.org/10.4324/9780429280726-2

Mupezeni, S., & Kriek, J. (2018). Out-of-school activity: A comparison of the experiences of rural and urban participants in science fairs in the Limpopo Province, South Africa. *Eurasia Journal of Mathematics, Science and Technology Education, 14*(8), Article em1577. https://doi.org/10.29333/ejmste/92041

Mupira, P., & Ramnarain, U. D. (2018). The effect of inquiry-based learning on the achievement goal-orientation of grade 10 physical sciences learners at township schools in South Africa. *Journal of Research in Science Teaching, 55*(6), 810-825. https://doi.org/10.1002/tea.21440

Naidoo, K. (2021). Understanding self-regulated learning and self-efficacy in project-based activities: Case studies of selected Eskom Expo for Young Scientists alumni. In J. Butler-Adam (Ed.), *STEMI Olympiads and Competitions Community of Practice Conference* (pp. 65-87). South African Agency for Science and Technology Advancement. http://www.saasta.ac.za/saasta_wp/wp-content/uploads/2022/06/2021-STEMI-Community-of-Practice-Conference-Proceedings.pdf

Ngcoza, K. M., Sewry, J., Chikunda, C., & Kahenge, W. (2016). Stakeholders' perceptions of participation in science expos: A South African case study. *African Journal of Research in Mathematics, Science and Technology Education, 20*(2), 189-199. https://doi.org/10.1080/18117295.2016.1192238

Okitowamba, O., Julie, C., & Mbekwa, M. (2018). The effects of examination-driven teaching on mathematics achievement in grade 10 school-based high-stakes examinations. *Pythagoras, 39*(1). https://doi.org/10.4102/pythagoras.v39i1.377

Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education, 25*(2), 177-196. https://doi.org/10.1007/s10972-014-9384-1

Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review, 14*, 47-61. https://doi.org/10.1016/j.edurev.2015.02.003

Penn, M., & Ramnarain, U. D. (2022). South African grade 12 science students' understandings of scientific inquiry. *Science & Education, 31*(3), 635-656. https://doi.org/10.1007/s11191-021-00259-2

Ramnarain, U. D. (2020). Exploring the autonomy of South African school science students when doing investigative inquiries for a science fair. *Eurasia Journal of Mathematics, Science and Technology Education, 16*(12), Article em1911. https://doi.org/10.29333/ejmste/9128

Ramnarain, U. D., & Hlatswayo, M. (2018). Teacher beliefs and attitudes about inquiry-based learning in a rural school district in South Africa. *South African Journal of Education, 38*(1), 51-61. https://doi.org/10.15700/saje.v38n1a1431

Ramnarain, U. D., & Hobden, P. (2015). Shifting South African learners towards greater autonomy in scientific investigations. *Journal of Curriculum Studies, 47*(1), 94-121. https://doi.org/10.1080/00220272.2014.966153

Ramnarain, U. D., & Schuster, D. (2014). The pedagogical orientations of South African physical sciences teachers towards inquiry or direct instructional approaches. *Research in Science Education, 44*(4), 627-650. https://doi.org/10.1007/s11165-013-9395-5

Reddy, V., Visser, M., Winnaar, L., Arends, F., Juan, A. L., Prinsloo, C., & Isdale, K. (2016). *TIMSS 2015: Highlights of mathematics and science achievement of grade 9 South African learners*. Human Sciences Research Council. http://hdl.handle.net/20.500.11910/10673

Schmidt, K. M., & Kelter, P. (2017). Science fairs: A qualitative study of their impact on student science inquiry learning and attitudes toward STEM. *Science Educator, 25*(2), 126-132. https://eric.ed.gov/?id=EJ1132100

Smith, R., Snow, P., Serry, T., & Hammond, L. (2021). The role of background knowledge in reading comprehension: A critical review. *Reading Psychology, 42*(3), 214-240. https://doi.org/10.1080/02702711.2021.1888348

Spaull, N. (2013). Poverty & privilege: Primary school inequality in South Africa. *International Journal of Educational Development, 33*(5), 436-447. https://doi.org/10.1016/j.ijedudev.2012.09.009

Spaull, N., & Jansen, J. D. (2019). *South African schooling: The enigma of inequality*. Springer. https://doi.org/10.1007/978-3-030-18811-5

Spaull, N., & Pretorius, E. (2019). Still falling at the first hurdle: Examining early grade reading in South Africa. In N. Spaull, & J. Jansen (Eds.), *South African schooling: The enigma of inequality* (pp. 147-168). Springer. https://doi.org/10.1007/978-3-030-18811-5_8

Spaull, N., Pretorius, E., & Nompumelelo, M. (2020). Investigating the comprehension iceberg: Developing empirical benchmarks for early-grade reading in agglutinating African languages. *South African Journal of Childhood Education, 10*(1). https://doi.org/10.4102/sajce.v10i1.773

Stott, A. E. (2017). The effectiveness of a conceptually focused out-of-class intervention on promoting learning of electricity by township learners. *African Journal of Research in Mathematics, Science and Technology Education, 21*(3), 304-315. https://doi.org/10.1080/18117295.2017.1371981

Stott, A. E. (2018). Are instructivist pedagogies more appropriate for learning the sciences in South African low-quintile schools than western literature suggests? *Journal of Education, 71*, 39-57.

Stott, A. E. (2019). The efficacy of an extracurricular inquiry programme on grade 8 and 9 South African low quintile learners' science learning. *African Journal of Research in Mathematics, Science and Technology Education, 23*(2), 157-168. https://doi.org/10.1080/18117295.2019.1630112

Stott, A. E., & Beelders, T. (2019). The influence of science reading comprehension on South African township learners' learning of science. *South African Journal of*

Science, *115*(1-2), 72-80. https://doi.org/10.17159/sajs.2019/5146

Stott, A. E., Dreyer, H., & Venter, P. (2015). Consequences of the progression law in the FET phase: a case study. *Journal of Education*, *63*, 89-109. http://joe.ukzn.ac.za/Libraries/No_63_2015/Consequences_of_the_progression_law_in_the_FET_phase_A_case_study.sflb.ashx

Stott, A. E., & Duvenhage, M. (2023). The response of higher-achieving South African learners from poverty to an extracurricular mathematics-guided problem-based learning programme. *African Journal of Research in Mathematics, Science and Technology Education*, 1-14. https://doi.org/10.1080/18117295.2023.2275857

Taylor, D. (2011). 'They are using laptops, we are using boxes': Township learners' conceptions of Expo. *African Journal of Research in Mathematics, Science and Technology Education, 15*(1), 67-79. https://doi.org/10.1080/10288457.2011.10740702

Willingham, D. T. (2008). Critical thinking: Why is it so hard to teach? *Arts Education Policy Review, 109*(4), 21-32. https://doi.org/10.3200/AEPR.109.4.21-32

Young, M. (2013). Overcoming the crisis in curriculum theory: A knowledge-based approach. *Journal of Curriculum Studies, 45*(2), 101-118. https://doi.org/10.1080/00220272.2013.764505

Zacharia, Z. C., Manoli, C., Xenofontos, N., de Jong, T., Pedaste, M., van Riesen, S. A. N., Kamp, E. T., Mäeots, M., Siiman, L., & Tsourlidaki, E. (2015). Identifying potential types of guidance for supporting student inquiry when using virtual and remote labs in science: A literature review. *Educational Technology Research and Development, 63*(2), 257-302. https://doi.org/10.1007/s11423-015-9370-0

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