

UPPER-SECONDARY SCHOOL STUDENTS' APPROACHES TO SCIENCE EXPERIMENTS IN AN EXAMINATION DRIVEN CURRICULUM CONTEXT

Tamirirofa Chirikure

Introduction

Science experiments, as a form of practical work, have long been regarded as the epitome of *doing science*. While there are strong arguments for doing science experiments, their effectiveness in developing substantive and procedural knowledge has been questioned with students either failing to do what was expected and/or learn what was intended (Abrahams & Millar, 2008; Abrahams & Reiss, 2012). Students' shortcomings when doing experiments have led some to design programmes and activities to improve students' understanding and application of substantive and procedural knowledge (Roberts, 2009; Roberts et al., 2010; Schalk et al., 2013). Students' retrieval and application of substantive and procedural knowledge during minds-on-hands-on engagement with science experiments translates into distinguishable approaches. Approaches to science experiments refer to students' minds-on-hands-on engagement when they plan and conduct science experiments. Roberts et al. (2010) established that students use an iterative, linear or divergent approach as influenced by their residual substantive and procedural knowledge. While the three approaches have been sufficiently characterised, there is a dearth of literature on the profiling of students' approaches to science experiments based on their self-reporting.

Profiling students' approaches through self-reporting is not new. However, this has been restricted to approaches to learning which have been extensively researched leading to the emergence and evolution of the dichotomy of deep and surface approaches to learning (Biggs, 1991; Cano, 2007; Chin & Brown, 2000; Chiou et al., 2013; Marton & Saljo, 1997; Minbashian et al., 2004; Tsai, 2004). Chirikure et al. (2018) extended this knowledge by exploring how students approach chemistry experiments from a learning perspective but fell short of investigating how they engaged with the processes of designing, planning, data collection, processing and interpretation. In an earlier study Lubben et al. (2001) gave insight into university undergraduate first-year students' point and set reasoning when they generate, process and interpret measurement data while Kanari and Millar (2004) explored how students collect and interpret data in pendulum experiments. The focus on students' engagement in science domain specific experiments apparently obviates the fact that students often import ways of working from one science domain to another. If the same skills set is required, this leads to the crystallisation of specific approaches. A generalised profiling of students' approaches to science experiments can give insight into their understanding of the practice of science and how scientific knowledge is generated.



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Abstract: *This research explored upper-secondary school students' approaches when they engage in planning and conducting science experiments. Approaches to science experiments are important because they provide insight into students' scientific reasoning and their enactment of scientific methods. An explanatory mixed-methods design was employed to determine and explain students' approaches to science experiments. Data were generated by administering a 15-item Approaches to Science Experiments Questionnaire (ASEQ) on 211 participants and interviewing a smaller sample of 33. The linear approach was predominant while the divergent approach was least adopted by the participants. The teaching-learning context, substantive and procedural knowledge lead to specific approaches and the emergence of subcategories of the three broad approaches. Capable students engaged in a self-directed iterative approach while external help resulted in an assisted iterative approach. Rigid and contrived linear approaches were a result of time constraints, substantive and procedural shortcomings. Scattergun and blanking divergent approaches emerged from extreme weaknesses in substantive and procedural knowledge. Assessing practical skills through long-term projects is recommended to focus more on developing students' scientific reasoning and process skills. Research with the ASEQ in other teaching-learning cultures, observing students in action and analysing their write-ups could provide deeper insights into approaches to science experiments.*

Keywords: *science experiments, divergent approach, iterative approach, linear approach, mixed methods.*

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Science Experiments in Context and Their Worth

The ability to do science experiments is highly regarded in the Zimbabwean Advanced Level science curriculum. The majority of the schools use curricula designed by the Ministry of Primary and Secondary Education (MoPSE) and examined by the Zimbabwe School Examinations Council (ZIMSEC) while a minority follow the Cambridge International Examinations (CIE) curriculum. However, both curricula have similar assessment objectives in relation to practical work. For example, their Chemistry syllabi indicate that students will be assessed on their ability to plan and carry out experiments including the evaluation of methods and suggesting possible improvements (Cambridge International Examinations, 2016; Ministry of Primary and Secondary Education, 2015). Students' competence in planning and conducting science experiments is assessed through a practical examination by both the ZIMSEC and CIE. This component has a weighting of up to 11.5% of the final examination in each science subject.

Science experiments, in the context of this research, are "practical activities in which students are not given a complete set of instructions to follow, but have some freedom to choose the procedures to use, and to decide how to record, analyse and report the data collected" (Millar, 2010, p. 2). This conceptualisation of science experiments advances the idea of open-endedness. In the context of the current study the experiments done by Advanced Level students are not necessarily open-ended, the problem questions are provided by the science teachers (during syllabi coverage) and the examiners in final examinations. This is apparently a compromise to achieve a uniform assessment of practical skills especially for the Cambridge examinations which are administered to students in many countries across the world. In contrast, the Dutch curriculum has shifted towards industry-inspired design practices with a view to promoting meaningful learning (Stammes et al., 2020).

Doing science experiments is believed to enable students to actively construct knowledge (Škoda et al., 2015), develop scientific reasoning, and science process skills while practically experiencing how scientists work to generate scientific knowledge (Abrahams & Millar, 2008; George-Williams et al., 2020; Kanari & Millar, 2004; Toplis & Allen, 2012). Minds-on activities such as science experiments are also essential for internalising procedures paramount for solving contemporary problematic situations occasioned by disease, hunger, environmental pollution and an exponential increase in the world population leading to knowledge generation (Bernard et al., 2019; Hammer & Manz, 2019). The emphasis on science experiments at high school level is also informed by the global advocacy on Science, Technology, Engineering and Mathematics (STEM) education given the universal nature of (science) process skills.

Millar (1989) described doing science as a craft and advised against a singular algorithmic scientific method by suggesting that science experiments involve "the exercise of skill in deciding what to observe and selecting which observations to pay attention to in interpreting and drawing inference, in drawing conclusions from experimental data, even in replicating experiments" (p. 168). Regrettably, students often misconstrue science experiments as activities characterised by a singular scientific method with a rigid experimental procedure (Moeed, 2013). This misplaced focus on algorithms often leads to a superficial understanding of scientific reasoning and practice (Windschitl et al., 2007). In this regard, Tang et al. (2010) argued for a change in the enactment of science experiments in order to shift from obligatory ineffectual learning to productive cognitive engagement.

A Framework for Students' Approaches to Science Experiments

Students' approaches to science experiments are encapsulated in how they use substantive and procedural knowledge to plan and conduct their own experimental procedures, process, analyse and interpret data. Arguably the most elaborate approach to science experiments is derived from the problem solving chain (Woolnough & Allsop, 1985) which Roberts et al. (2010) called the iterative approach to science experiments. Linear and divergent complete the triad of approaches which can be adopted by students as they cognitively engage with science experiments.

The iterative approach can be consolidated into five phases: designing and planning; performance and data recording; data processing and interpretation; reflection and reporting. The first phase of designing and planning starts once the students are presented with a problem. The students start with problem perception and reformulation. According to Woolnough and Allsop (1985), "the students analyse the factors relevant to the question, assemble the appropriate information; create or consider various ways of attacking the problem, select the best option and then plan the science investigation" (p. 51). The methodological implication of highlighting problem perception and reformulation is that there is emphasis on problem sense-making which discourages students from



diving headlong into writing the experimental steps without a good understanding of what is required of them. Problem perception and reformulation is therefore the beginning of the planning part of this phase. Planning may also involve formulating a hypothesis especially when the science investigation falls under quantitative analysis. Once the students identify a feasible way of doing the science investigation, they then proceed to outline a series of steps that consist of the experimental procedure to be used. The designing part of this phase involves a description and often a diagrammatic representation of the set-up of the apparatus to be used.

The second phase of performance and data recording phase involves executing the proposed experimental procedure. The students will set the apparatus and corresponding experimental conditions to collect the relevant data. During this stage, they will make the necessary measurements and/or observations and capture this data in an appropriate manner such as tables. Coupling performance with data recording ensures that students are reminded of the need to write down the relevant data from measurements and/or observations as they occur. Such data were often captured in tables with appropriate headings.

During the third phase of data processing and interpretation, students often transform the collected data to determine derived values in quantitative analysis. For example, in a science investigation to determine the rate of a chemical reaction, concentration and time measurements will be transformed to give the rate of reaction at various stages of the reaction. Numerical data can also be used to construct graphs from which extrapolations or interpolations can be done. This is followed by data sense making and providing an answer to the initial problem. In qualitative analysis students use their observations to make deductions based on known characteristics of the various inorganic ions and organic functional groups.

The fourth phase of reflection is when students do an evaluation of their results. Students should auto-assess and make judgements on whether their results make sense or not in relation to the original problem. If the results deviate from their expectations, then they (students) can go back to reformulate, redesign or improve their techniques and collect new data with the aim of obtaining better results. In essence, reflection should not be enacted as a time specific process done after data processing. Reflection on practice defines iteration during a science investigation. Hence, the phases in the iterative approach are not done one after another in a linear and unidirectional process. Most of them are done concurrently with continuous modification of the proposed plan (Hodson, 2009).

The fifth and final phase of reporting is done, in most cases, when the students feel they have the sufficient results and correct interpretation. In typical science experiments, apart from the results, reporting includes the experimental design and if necessary, details of why the experimental design did not work. Reporting should ideally reflect that doing a science investigation is a messy process which does not always lead to success although valuable lessons are always learned.

When students use a linear approach, stages are done sequentially. The first stage is the same as in the iterative approach, which is problem perception and reformulation. Differences with the iterative approach are noticeable from the planning stage onwards. Students will come up with one experimental design (plan) and then see it through without necessarily minding about its appropriateness (Roberts et al., 2010). This might be because of using a procedure used before in a similar science investigation or as a direct consequence of limited autonomy. The Science teachers might suggest the best experimental procedure to use and out of trust, the students do not see it necessary to consider alternative ways of doing the science investigation. The students don't always appreciate the need to constantly review their plan, experimental design or techniques in order to do any necessary changes leading to better results. The same can be said of the data processing and interpretation stages. Students tend to use predetermined ways of transforming the data and do not always give the interpretations that match the results. Generally, there is limited reflective practice and learning from the data generated. Consequently, the success rate of students associated with a linear approach is lower than that of their counterparts using the iterative approach. An emphasis on neatness by the teachers can also lead to this approach. Students will prioritise pleasing their teachers at the expense of reflecting the messiness of doing science experiments.

A divergent approach is when students find it extremely challenging to come up with a plausible experimental procedure (Roberts et al., 2010). Students get stuck from the beginning, in problem perception and reformulation. A limited conceptual understanding and failure to link theory with practical work might explain this. Students then fail to come up with a workable experimental procedure, make wrong choices of materials and fail to understand the basis of data collection. If students manage to collect some data, the processing is often flawed, leading to incorrect conclusions. Students who use a divergent approach are generally devoid of reflective practice. They never revisit their experimental designs which would potentially lead to improvements. Consequently, these students are unlikely to succeed when doing science experiments.



The current research focused on determining upper-secondary school students' approaches to science experiments as well as giving perspective to the adoption of observed approaches. The key research questions were:

1. How do upper-secondary school students approach science experiments?
2. Why do upper-secondary school students approach science experiments the way they do?

Research Methodology

General Background

This research adopted a pragmatic paradigm and mixed-methods approach (Creswell & Creswell, 2018; Teddlie & Tashakori, 2009) to quantitatively explore the students' approaches and use qualitative data to explain why students used specific approaches. A mixed-methods allowed the researcher to make use of appropriate methods aligned with either quantitative or qualitative approaches (Creswell, 2017). An explanatory design (Creswell & Creswell, 2018) was employed where quantitative data were generated and analysed before interviewing selected students to obtain qualitative data. The qualitative data were meant to give meaning to the quantitative data. The data were generated during the participants' final upper-secondary school year, a week after the mid-year examinations. This was three months before the commencement of the final Advanced Level public examinations. The mid-year examinations serve as a dry run for the final examinations so, the assumption was that the students were at their optimum performance levels and their approaches were well defined.

Participants

The participants were 211 upper-secondary school science students from eight conveniently sampled Zimbabwean schools. Challenges with accessing schools offering science subjects at Advanced Level meant this was the best number of participants. There is no consensus in literature on the minimum sample size for factor analysis with figures ranging from 30 to 300 (Cohen et al., 2018) but 100 is general acceptable (MacCallum et al., 1999). Tabachnick and Fidell (2007) considered 211 as a fairly good sample size. Five of the schools were enacting the MoPSE curriculum examined by ZIMSEC while the remaining three were enacting the CIE curriculum. The MoPSE curriculum is largely similar to CIE due to the historical ties between Zimbabwe and the United Kingdom. The localisation of high school examinations was only completed in 2002 but retaining the major components of the CIE curriculum. The students' ages ranged from 17 to 19 years. Apart from the theory lessons, each school had one dedicated two hour practical sessions for each science subject. All the participants did at least two science subjects and Mathematics (Table 1). Given the varying subject combinations, the findings of the current study must be read with the understanding that even students from the same school did not necessarily have the same experiences of doing science experiments.

Table 1

Distribution of students by subject combination

Subject combination	Number of students
Biology, Chemistry, Mathematics	79
Chemistry, Physics, Mathematics	83
Biology, Chemistry, Physics, Mathematics	39
Total	211

All the students consented to completing the ASEQ and participated in one-on-one interviews. Pseudonyms were used in reporting the data to protect the identity of the students. In addition, there was only a maximum of five girls doing science subjects in each school so, no demographic data relating to gender was collected as this would have compromised the identity of the female students. Furthermore, there was no intention to explore gender differences with respect to the students' approaches to science experiments.



Instrument and Procedures

A 15-item Approaches to Experiments Questionnaire (ASEQ) was used to determine the students' approaches. The ASEQ was designed for the purposes of the current research based on the theoretical framework. Students self-reported on each item based on a Likert scale ranging from *always* to *never* (always = 5; often = 4; sometimes = 3; seldom = 2; never = 1).

The validation of the ASEQ was done by establishing its factor structure through exploratory factor analysis (EFA) and the clarity of the items through participants' feedback. A pilot sample of 34 students (greater than the minimum of 30 from literature) from one school was used. The Kaiser-Meyer-Olkin (KMO) measure was greater than .6 and the Bartlett test was statistically significant ($p < .05$) (Table 2) hence a principal component analysis was performed (Cohen et al., 2018).

Table 2

KMO and Bartlett's test output statistics

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.895
Bartlett's Test of Sphericity	χ^2	150.112
	<i>df</i>	21
	<i>p</i>	<.001

An oblique direct oblimin rotation was performed because the factor correlation matrix had a correlation of .379 which exceeded the Tabachnick and Fidell threshold of .32 (Tabachnick & Fidell, 2007). Three factors had Eigen values greater than the recommended cut-off of one (Cohen et al., 2018) and the total variance explained was 80.1%. The factors were named *iterative*, *linear* and *divergent* based on the theoretical framework. Their respective overall Cronbach alpha coefficients were .871; .868 and 0.814 indicating a high reliability in assessing students' approaches to experiments. The mean correlation coefficient between factors was .38 thus indicating convergent and discriminant validity. There were no issues about the clarity of the items so, no modifications were made to the original questionnaire draft.

Face-to-face open-ended interviews (McMillan & Schumacher, 2014; Yin, 2016) were conducted to probe selected students with the aim of getting insight into their adoption of specific approaches. Open-ended questions allowed the students to express themselves in their own words and engage in reflexivity. The interviewees were asked to describe how they went about planning and carrying out science experiments and why they made specific choices. The interviews were audio recorded with the permission of the participants. The audio transcripts were subjected to member checking for respondent validation (Denzin & Lincoln, 2018).

Data Analysis

Exploratory factor analysis (EFA) was performed to ascertain the factor structure of the ASEQ with a larger sample and determine if any factors were to be extracted. EFA with an oblique direct oblimin rotation was performed with the orthogonal factors as *iterative*, *linear* and *divergent*. Confirmatory factor analysis (CFA) was employed to check for construct, convergent, and discriminant validity and to ascertain the structure given that the factors were derived from a theoretical framework (Cohen et al., 2018).

The mean agreement scores were used to determine the approach for each student. Each student's mean agreement scores by approach were computed and the highest score was used to determine a particular student's approach to science experiments.

The qualitative data from the face-to-face open-ended interviews were subjected to inductive analysis (McMillan & Schumacher, 2014). Two critical friends, who were colleagues in science education, assisted with checking the accuracy of the coding and interpretation of the data. The emergent patterns lead to themes from which subcategories of the three approaches to science experiments were conceptualised.



Research Results

Quantitative Results

The factor structure of the ASEQ was established through exploratory factor analysis (EFA). The Kaiser-Meyer-Olkin (KMO) measure was greater than .6 and the Bartlett test was statistically significant ($p < .05$) (see Table 3) hence principal component analysis was performed (Cohen et al., 2018).

Table 3

KMO and Bartlett's test output statistics

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.937
Bartlett's Test of Sphericity	χ^2	2763.820
	<i>df</i>	105
	<i>p</i>	<.001

An oblique direct oblimin rotation was performed because the factor correlation matrix had a correlation of .354 which exceeded the Tabachnick and Fidell threshold of .32 (Tabachnick & Fidell, 2007). All the three factors had a factor loading greater than .50 and none had cross-loadings (Table 4) hence, they were all retained (Cohen et al., 2018). The Eigen values were all greater than one and the total variance explained was 78.5%. The respective overall Cronbach alpha coefficients were .929; .928 and 0.814 indicating a high reliability in assessing students' approaches to experiments. A mean correlation coefficient between factors of .35 indicated convergent and discriminant validity. The factor mean scores showed that the students scored high on both linear ($M = 3.46$, $SD = 1.34$) and iterative ($M = 3.09$; $SD = 1.36$) but low on the factor divergent ($M = 2.02$ $SD = 1.04$). Consequently, it can be deduced that linear or iterative approaches to science experiments were more frequently used.

Table 4

Rotated factor loadings, Cronbach's alpha values, means and standard deviations for the four factors of the ASEQ

	Factor 1: Iterative	Factor 2: Linear	Factor 3: Divergent
Factor 1: Iterative ($\alpha = .929$, mean = 3.09, $SD = 1.36$)			
ASEQ1	.823		
ASEQ4	.815		
ASEQ7	.813		
ASEQ10	.815		
ASEQ13	.862		
Factor 2: Linear ($\alpha = .928$ mean = 3.46, $SD = 1.34$)			
ASEQ2		.848	
ASEQ5		.819	
ASEQ8		.829	
ASEQ9		.825	
ASEQ14		.867	
Factor 3 – Divergent: ($\alpha = .814$, mean = 2.02 $SD = 1.04$)			
ASEQ3			.786
ASEQ6			.731
ASEQ9			.723
ASEQ12			.763
ASEQ15			.734

*Total variance explained: 74.2%.



Confirmatory factor analysis (CFA) further confirmed the structure of the ASEQ. The hypothesis was: Students' approaches to science experiments have a three-factor structure. Three tests for the goodness of fit were considered: the Chi-squared test, the Comparative Fit Index (CFI) and the Root Mean Square Error of Approximation (RMSEA) (Kline, 2015). The ASEQ Chi-square per degree of freedom was 120.748 ($df = 87$; $p = .010$) indicating a poor fit given that $p < .05$. However, pragmatic indicators of goodness of fit showed that the model was a good fit (see Table 5).

The RMSEA, which is regarded as a very informative criterion in covariance structure modelling (Byrne, 2016), was less than .05 indicating a good fit. Because of the achieved Chi-squared value, other fit indices were used to evaluate the goodness of fit of the three-factor structure together with the CFI. The three-factor was a superior fit based on the CFI, Normed Fit Index (NFI), Incremental Fit Index (IFI) and Tucker-Lewis index (Tulis et al., 2016) which were all greater than .950. The model-fit was marginally adequate based on the Relative Fit Index (RFI) whose value was less than .950. The sample (211) for this study just exceeds the minimum requirement. Based on the RMSEA and CFI values it can be concluded that the ASEQ had sufficient fit with convergent, construct, and discriminant validity (Cohen et al., 2018).

Table 5

Selected goodness-of-fit statistics for the hypothesized three-factor CFA model

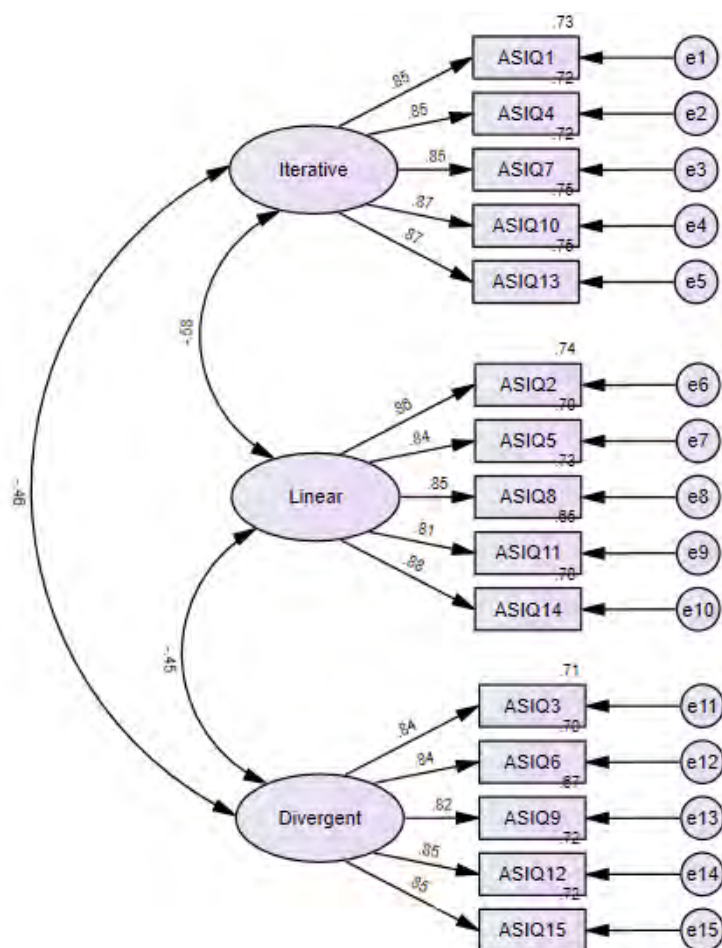
Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.958	.949	.988	.985	.988
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000
RMSEA					
Model	RMSEA	LO 90	HI 90	PCLOSE	
Default model	.043	.022	.060	.728	
Independence model	.352	.341	.364	.000	

As shown in Figure 1, all the factor loadings were relatively high ($> .80$), and statistically significant (Cohen et al., 2018). It can therefore be concluded that all the observed variables (ASEQ items) were strongly correlated to the ascribed latent variables (approaches to science experiments).



Figure 1

Standardised estimates for the three-factor model of approaches to science experiments.



The mean scores for each student were computed to determine the prominent approach for each one of them. The highest mean score was used to determine each student's prominent approach and at least 50% of the participants were categorised under the linear. Table 6 shows examples of how individual students' approaches to science experiments were determined.

Table 6*Individual students' prominent approaches*

Participant	Mean score			Prominent approach	Frequency (n = 211)
	Iterative	Linear	Divergent		
Student 1	4.32*	3.51	1.54	Iterative	79
Student 71	3.25	4.53*	2.12	Linear	106
Student 135	2.46	2.55	4.01*	Divergent	36

*Highest mean score

After profiling each student, interview participants were selected based on their prominent approaches. Interviews were conducted until data saturation occurred. A total of 33 students were interviewed: iterative - 11; linear - 16; divergent - 6.

Qualitative Results

Significant insights emerged from the systematic analysis of the interview data. The students who fell under the iterative approach gave detailed descriptions of how they went about planning and carrying out their science experiments. They comprehensively outlined how they dealt with any challenges they encountered while doing the science experiments which often involved retracing their steps in the experimental design to identify any errors and redoing the science investigation until they were satisfied with their data. One student's response was a typical example of those that were categorised under the iterative approach:

I prepare for all practical sessions thoroughly by studying all the theory we do in each topic. I also spend time practising doing the calculations and drawing graphs, for example the rate of reactions, the order of reaction and enthalpy changes. It helps when you know the calculations because you can tell from the investigation problem what data you will need to generate and how you process it. You can also tell if your own data are sensible or not and make decisions to either process it, redo the experiments, or go ahead and explain the anomalies. It also helps to repeat the experiments because it improves your accuracy..... After doing the calculations I always check to see whether the results conform to the theory I know. If not, I repeat and collect new data. If the results are similar, then I have to find a way of explaining them. (ST51)

Five students indicated that they often asked for help from their science teacher or the laboratory technician when they were convinced that they were not doing the science investigation the right way. One of them had this to say:

Sometimes I ask for pointers from the teacher or lab technician when I feel I am really stuck and cannot help myself. I do it as a last resort during our regular practical session because I know I will not be able to ask them during the final examinations. For example, if I am in doubt, I ask the teacher to check if my data is sensible. If not, I modify my experimental design and do the investigation all over again. (ST116)

A total of 106 students fell under the linear approach to science experiments and 16 of them were interviewed. These students came up with only one way of doing a science investigation based on what they could remember from practical work done before and what their science teacher said in previous post practical discussions. The quotes below illustrate this:

When it comes to experiments, I often come up with a plan which I carry out to completion. I do my best with the knowledge that I have for a specific topic related to the investigation. Once I get the results, I interpret them based on the theory we learn in class. It's not always easy for me to link the experiments to theory. Sometimes the results don't match the theory, so I just leave them like that. (ST7)

Teaching strategies also seemed to promote a linear approach. When the Science teachers gave feedback on the experiments, they often outlined one way of doing it. One of the interviewed students said:

I am always pressed for time when we do science experiments. When I process my data, sometimes I realise it doesn't make sense but because of limited time I can't repeat the investigation. When we get feedback from our teacher after each practical session, he gives us a model answer on the experimental design. This is helpful because we learn the correct way of setting up the experiment, collecting the required data, and processing it. (ST89)

Thirty-six students were classified under the divergent approach. Substantive and procedural knowledge deficiencies meant students falling under this approach did not attempt investigative questions, could not design a feasible experimental procedure, or could not generate sensible data. They did not know what data to collect and how to process it. One of the students said:

I am very weak in science experiments. For example, in our last practical session, I did not know how to determine the order of reaction so, I could not come up with a feasible experimental procedure. I did not know what data to collect and how to set up the experiment. I just wrote something. (ST37)



During end of term examinations, four of the interviewed students with a divergent approach indicated that they did not attempt science investigation questions at all. They just focused on the sections which came with an experimental procedure like ST201 who said, "Science experiments are very challenging for me especially under examination conditions. I just focus on the sections where the experimental procedure is provided. I can't waste time on experiments when I know can't do much".

Discussion

The results of both EFA and CFA confirm the existence of a three-factor structure leading to three definite approaches to science experiments: iterative, linear and divergent. The prominence of the linear approach is unexpected given the amount of time dedicated to practical work and science experiments in particular in the upper-secondary school science curriculum. The ideal outcome would have been the results skewed towards the iterative approach given that the data was collected at a time when the students were apparently at optimum performance level regarding science experiments. The relatively low frequency of the divergent approach tallies with expectations as students at this level should have a good grasp of the scientific method after doing several science experiments in at least two of Biology, Chemistry, and Physics.

More than half of the participants (106 of 211) used the linear approach when planning and carrying out science experiments. The use of the linear approach was in part a result of limited substantive and procedural knowledge. Students lacked the requisite conceptual understanding and competence in science process skills and reflexivity. Consequently, students consciously mastered one way of doing things as a practice which inherently hindered iteration especially in the planning stage of a science investigation. This leads to a *rigid linear approach* where students come up with one experimental procedure and stick with it no matter what their results look like. This arises out of weaknesses in scientific reasoning hindering conceptual understanding (Kisiel et al., 2012), and incompetence in one or more process skills (Kanari & Millar, 2004). Erlina et al. (2018) attribute this to ineffective teaching strategies which deviate from the philosophy of science experiments. The science teachers were reported to be focusing on ideal procedures and data during revision while disregarding the learning derived from other data sets. This focus on conformity with canonical science emerges as a hindrance to developing a nuanced view and practice of science experiments as it leads to predetermined interpretation of results and less productive approaches.

Of the 16 students interviewed under the linear approach, 10 alluded to time constraints as a significant factor in their decision to stick to a planned experimental procedure and the absence of reflection and iteration during science experiments. Given that they were able to identify weaknesses in their experimental procedures but were restricted by time, their approach can be described as a *contrived linear approach*. Perhaps time restrictions are inadvertently creating a less desirable enactment of the scientific method and understanding of how scientists work.

The less than 50% (79 of 211) under the iterative approach corroborate findings by scholars who established that only a few students were associated with the iterative approach (Hackling & Garnett, 1995; Hammann et al., 2008; Watson, 1994). Those who used the iterative approach had sound substantive and procedural knowledge as well as the ability to reflect on own work and correct any weaknesses identified. These students had a developed sense of the scientific method driven by their desire to achieve good grades. When students worked independently in planning and carrying out science experiments, a *self-directed iterative approach* is manifested. Four of the students interviewed under the iterative approach sought assistance from their teacher or laboratory technician when they got stuck. Improving experimental procedures and/or data based on external input can be described as an *assisted iterative approach*.

The students (36 of 173) who adopted a divergent approach apparently had weak substantive and procedural knowledge. Therefore, they used a *scattergun divergent approach* leading to experimental designs which were generally not feasible. Some students did not attempt science investigation questions during examinations because they did not know what to do. This can be described as a *blanking divergent approach*. In earlier studies, Hackling and Garnett (1995) and Watson (1994) also asserted that a divergent approach led to poor results and performances. Erlina et al. (2018) recommended inquiry-based teaching as a panacea to low scientific reasoning evident in a scattergun approach. This encompasses teaching students the various stages of a science investigation and alerting students to the fact that significant learning can be derived from errors (Metcalfe, 2017). Dealing with students' errors also helps in fostering self-regulatory learning and reflexivity (Tulis et al., 2016), important traits in the practice of science.

While, the quantitative data lead to the collective and individual profiling of upper-secondary school students'



approaches to science experiments, the qualitative findings extended the theoretical conceptualisation by establishing two subcategories in each approach to science experiments.

Conclusions

The focus of the current study leads to the administration of a purposefully designed ASEQ whose three-factor structure was validated through exploratory and confirmatory factor analysis. Many countries around the world assess high school students on their ability to plan and carry out experiments. Assuming that approaches to science experiments are culture specific, administering the ASEQ in other countries would provide deeper insights into the phenomenon.

Qualitative data supported the existence of iterative, linear and divergent approaches to experiments as well as subcategories as influenced by contextual factors and personal student attributes. The prominence of the linear approach and the existence of the divergent approach deduced from the means of the ratings, the distribution of the participants by approach, and the qualitative data suggests weaknesses in the enactment of science experiments inadvertently induced by the nature of the assessment and partly by the teaching strategies. A few options can be used to improve the situation. First, a shift from short-term to long-term science experiments would possibly remove time constraints and give students ample opportunities to attempt the work and move towards iteration. The long term science experiments could be assigned as group work to encourage cooperation, brainstorming and reflection between students reminiscent of how scientists work. Inevitably, this should be balanced with the challenges of integrating assessment and science experiments. In addition, the influence of assessment on approaches to science experiments merits further research. Second, adding a design element framed in industry-contextualised long-term science projects might also improve students' motivation and cognitive engagement thereby promoting the iterative approach. Third, science teachers could systematically employ teaching strategies which develop the iterative approach. A longitudinal study may be useful in tracking how students' approaches evolve during an entire course of study such as the two-year Advanced Level programme. Observing high school students doing science experiments and analysing students' write-ups might also yield more insight into their approaches and offset the pitfalls of self-reporting.

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Appendix A

Thank you for agreeing to complete this questionnaire.

The questionnaire is about how you plan and conduct science experiments in the Advanced Level science subjects you do (Biology, Chemistry, and Physics). Please respond to each item as honestly as possible based on your knowledge of how work when doing science experiments. The questionnaire should take you about 10 minutes to complete.

* **Indicate your response to each item by writing "X" in the appropriate box.**

No.	Item	Never	Seldom	Sometimes	Often	Always
ASEQ 1	When planning a science investigation, I consider many options before settling on the most viable procedure.					
ASEQ 2	When asked to plan a science investigation, I come up with only one experimental procedure.					
ASEQ 3	In a science practical examination, I do not attempt an investigation question					
ASEQ 4	When planning and carrying out a science investigation, I reflect on what I am doing and make changes where necessary.					
ASEQ 5	I carry out a science investigation to completion even when I am not sure of the feasibility of my plan.					
ASEQ 6	I fail to design a feasible experiment when asked to do an investigation in science.					
ASEQ 7	After collecting experimental data for a science investigation, I check to see if it makes sense before processing it.					
ASEQ 8	I fail to identify weaknesses in my plan when I do science experiments.					
ASEQ 9	I leave important steps when I design an experiment for an investigation in science.					
ASEQ 10	When I process experimental data for a science investigation, I identify and discard outliers.					
ASEQ 11	I do not know how to correct weaknesses in my plan of a science investigation even if I identify them.					
ASEQ 12	When doing experiments in science, I fail to collect the required data.					
ASEQ 13	If the results a science investigation do not make sense, I revise my procedure and re-do the experiment(s).					
ASEQ 14	During an examination, I do not find time to re-do a science investigation even when I know the results do not make sense.					
ASEQ 15	When I plan experiments in science, I fail to figure out how the data will be processed.					

Notes for scoring:

Never = 1; Seldom = 2; Sometimes = 3; Often = 4; Always = 5

Iterative approach: items 1; 4; 7; 10; 13. Linear approach: items 2; 5; 11; 14. Divergent approach: items 3; 6; 9; 12; 15

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