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Assessing Ghanaian primary school pupils' scientific reasoning skills

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ABSTRACT

Science education seeks to equip individuals with the knowledge and skills needed to solve problems in society. To be successful in solving problems, one has to develop scientific reasoning skills. Although scientific reasoning skills are emphasized in the Ghanaian science curriculum, it is not explicitly taught, making it difficult to determine whether Ghanaian school children have developed them. This study, therefore, sought to assess the scientific reasoning skills of primary school pupils in Ghana. In doing so, efforts were made to investigate if differences existed in the scientific reasoning skills of boys and girls in different class levels in primary schools. A cross-sectional survey of 1,066 primary school pupils from 10 schools in Kumasi Metropolis in Ghana was conducted using the science P reasoning inventory. Means, standard deviation, independent sample t-test, and one-way multivariate analysis of variance were the statistical tools used to analyze the data obtained. The study revealed that class 4 and class 5 pupils demonstrated naïve scientific reasoning skills while class 6 pupils exhibited an intermediate level of scientific reasoning skills with no difference between boys and girls in each class. The study's findings highlight the need for a carefully structured and progressive curriculum that effectively develops scientific reasoning skills as pupils advance through different grade levels.

Keywords: scientific reasoning, primary school pupils, nature of science, experimentation, data interpretation

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INTRODUCTION

The goals of science education have evolved from learning scientific concepts to student acquisition of essential 21st century skills to contribute meaningfully to the development of society (Lemke, 2002; Turiman et al., 2012). For such expectations to materialize, learners have to develop scientific reasoning skills, which will culminate in the development of a citizenry who thinks critically (Bao et al., 2009; Kuhn, 2001). Thus, a premium has been placed on scientific reasoning as a necessary tool required for successful living in the 21st century (Kuhn, 2010; Turiman et al., 2012). The report of Organization for Economic Co-operation and Development (OECD, 2014) affirmed that innovative strategies that are based on scientific reasoning are the antidote to the 21st century problems. The report, therefore, suggests that scientific reasoning is one of the significant skills that learners are supposed to acquire if nations such as Ghana want to overcome their developmental challenges.

Scientific reasoning skills are a set of skills that are used to systematically explore a problem, formulate and test a hypothesis, design experiments and rationally interpret the results with the aim of developing meaning to make valid conclusions (Bao et al., 2009; Wenning & Vieyra, 2015; Zimmerman, 2007). The argument is that for proper derivation of the meaning of issues and arrival at valid conclusions, there ought to be scientific reasoning. Such scientific reasoning will prevent people from making hasty and invalid conceptualizations and generalizations, which could lead to misinformation and wrong cause of action. OECD (2014) has recommended that the focus of every curriculum in this 21st century should be on the development and nurturing of learners' scientific reasoning skills, which will help them become informed critical consumers of scientific knowledge that all individuals are expected to have during their lifetimes.

As Osterhaus et al. (2020) accentuated, learners should be able to understand scientific facts, conduct simple experiments and draw inferences from results to facilitate the successful development of their scientific reasoning skills. The process of scientific reasoning produces a holistic individual who becomes critical in dealing with issues. Such a person does not make haughty decisions but rather arrives at informed decisions having analyzed available information and options critically. Thus, the development of these skills at any level of education helps learners to become good reasoners and problem solvers leading to the making of informed decisions in their lives (Bao et al., 2009; Engelmann et al., 2016; Kambeyo, 2018; Lazonder & Wiskerke-Drost, 2015).

Due to developing trends and international standards in education, Ghana has placed a premium on developing learners' scientific reasoning skills in science education at the primary level (National

Council and Assessment [NaCCA], 2019). It is expected that developing primary school pupils' scientific reasoning skills will help Ghanaian pupils to critically examine issues and make informed decisions. Again, planners of the Ghanaian primary school curriculum believe that the development of pupils' scientific reasoning skills will have a long-term positive impact on the achievement of pupils and lay the foundation for science and science-related studies at higher levels of education (NaCCA, 2019). On the other hand, if the scientific reasoning skills of pupils are not well developed at the primary school level, it will have a rippling effect on their future development and success in science and science-related areas at higher levels of education. Thus, the emphasis on the scientific reasoning skills of students in the Ghanaian curriculum at the primary level is in the right direction since a focus on scientific reasoning abilities will lead to improved learning outcomes, which can affect the ultimate development of the country.

Although conscious efforts are being made to inculcate scientific reasoning in learners, the same cannot be said about how those skills are assessed. There are no explicit approaches earmarked for teachers to assess learners' scientific reasoning skills. This creates a situation, where it is difficult for stakeholders in education to determine whether learners have attained the required competency of scientific reasoning. The reality is that science education necessitates learners' logical skills and high degrees of reasoning skills (Riyanti et al., 2018). Educators are therefore encouraged to assess the level of learners' scientific reasoning skills to determine if learners are developing their reasoning abilities as they progress in education. It is pertinent, then, for Ghana's educational system to gauge how well learners are doing with regard to their scientific reasoning abilities. This will enable teachers to monitor learners' cognitive development in the classroom and ensure learners possess the appropriate reasoning skills necessary to understand and grasp the science learning material in a meaningful way (Adey & Csapó, 2012). The enhancement of students' scientific reasoning skills is the core reason to conduct this study. This paper sought to assess Ghanaian primary school pupils' scientific reasoning abilities.

LITERATURE REVIEW

Conceptualization of Scientific Reasoning Skills

Understanding of concepts is critical for successful teaching and learning (Layng, 2016). It is crucial for teachers and learners to have similar conceptualizations of concepts to be learned. Thus, for teachers to be successful in developing learners' scientific reasoning skills, these concepts ought to be understood. The description of scientific reason takes different forms albeit with some similarities. Here, we take a critical look at how scientific reasoning skills have been conceptualized.

Scientific reasoning skills is seen as the utilization of scientific processes to identify a problem and formulating appropriate experiments to arrive at valid conclusions (Bao et al. 2009; Wenning & Vieyra, 2015). The implication is that people who reason scientifically identify problems, formulate hypotheses, collect information and evaluate the hypothesis with evidence. This leads to the making of informed decisions. Such problem-solving activities are purposeful (Kuhn, 2010) and lead to the reflection on the process of knowledge acquisition and knowledge change (Morris et al., 2012). Bao et al. (2009) argue that scientific reasoning is a form of higher-order thinking that involves the systematic exploration of a problem to obtain a logical and appropriate solution. This process of acquiring knowledge through the formulation and testing of hypotheses helps students to become logical thinkers and problem solvers in society (Novia & Riandi, 2017).

In scientific reasoning, learners process information to make decisions and draw appropriate conclusions that go beyond direct experiences (Lawson, 2003; Thoron & Myers, 2012). Students who reason scientifically are able to use cognitive strategies to extend their understanding of problems that transcend the classroom. Such abilities aid learners to draw an effective conclusion, which is critical in developing meaning to solve scientific problems (Kuhn, 2010). As noted by Han (2013), scientific reasoning ability promotes learners' skills in the classroom in solving real-life 21st century problems in the environment.

Sub-Constructs of Scientific Reasoning Skills

There are several sub-constructs found in scientific reasoning skills (Carey et al., 1989; Lawson, 2004; Sodian et al., 1991). However, Koerber et al. (2005) summarized the various sub-constructs into three; "nature of science (NoS)," "experimentation (Expt)" and "data interpretation (DI)". Although these sub-constructs somehow have unique identities, for the effective development of scientific reasoning skills of learners in the classroom, they are expected to be treated in a blend rather than in isolation (Koerber et al., 2005; Nyberg et al., 2020; Osterhaus et al., 2020).

Kuhn (2002) explained that NoS construct involves the skills needed to understand scientific facts. This means that learners require the skill in NoS to be able to understand numerous scientific information. NoS construct encompasses the comprehension of the tentative nature of scientific theories and the cumulative and cyclical process of scientific inquiry (Carey et al., 1989). Akerson and Donnelly (2010) argue that science is made up of concepts and theories; therefore, learners require certain scientific reasoning skills in the classroom to comprehend these facts and theories to be able to formulate appropriate hypotheses. The ability to understand NoS helps learners to attach meanings to science concepts and differentiate between concepts and states of the world (Carey et al., 1989). In other words, learners are able to skillfully coordinate the relationship between hypothesis and evidence (Kuhn, 2010) when they master the understanding of NoS.

Expt sub-construct deals with the skills obtained in carrying out experiments. This is, where hypotheses formulated are tested through the conduction of systematic experiments (Koerber et al., 2015; Varma, 2014). Thus, scientists conduct systematic experiments on identified problems to obtain appropriate data. Based on the experiments' data, scientists can make valid interpretations of complex and challenging data patterns (Koerber et al., 2015; Kuhn, 2010). Expt process unearths the differences between testing a hypothesis and producing an effect (Osterhaus et al., 2020). Lawson (1992) believes that Expt sub-construct in scientific reasoning helps learners to test their predictions with a controlled experiment and this helps them in obtaining a deeper understanding of concepts without learning by rote.

DI sub-construct deals with knowledge used by a scientist in explaining the trends of data (Koerber et al., 2015). Osterhaus et al. (2020) emphasized that DI sub-construct is, where data patterns obtained from experiments are explained to make informed interpretations and conclusions. Therefore, to arrive at rich conclusions, DI construct in scientific reasoning cannot be overlooked.

Koerber et al. (2015) underscored that primary school pupils possess advanced levels of scientific reasoning skills in NoS sub-construct, although their understanding was not coherent. This showed that primary school children were able to reason scientifically when they were required to formulate a hypothesis. Similar conclusions were drawn by Abate et al. (2020) who asserted that primary school children are good at items that deal with facts and theories. However, they exhibit deficiencies when required to conduct an experiment to make a valid conclusion. Osterhaus et al. (2019) also demonstrated that many elementary (primary) school children demonstrate weakness when assessing the relation between data patterns. Thus, children have difficulties interpreting data from experiments to draw effective conclusions. This inhibits their ability to make appropriate inferences. Osterhaus et al. (2020), therefore, suggested that continuous development and nurturing of the reasoning abilities of children in conducting experiments and interpreting results will help them make informed decisions as they progress in life.

Levels of Scientific Reasoning

Three levels of scientific reasoning skills have been identified (Kuhn, 2010; Osterhaus et al., 2020). These levels are the naïve level of reasoning (low), intermediate level of reasoning (middle) and advanced level of reasoning (highest). The naïve form of reasoning is the lowest level of scientific reasoning skills (Kuhn, 2010; Osterhaus et al., 2020). They are primarily simplistic scientific reasoning skills formed before systematic learning (Fisher, 1985; Kuhn, 2010). Kuhn (2010) believes that learners at the naïve level have knowledge of the difference between how to produce effect and test formulated hypothesis and also understand that knowledge of effect production is not an appropriate example of a theory. Sodian et al. (1991) underscored that 8-year-old children at the naïve level had knowledge of the difference between the formulation and testing of a hypothesis. Again, children with naïve reasoning believe that scientists invent things. Therefore, they are not primarily interested in data as a basis for making conclusions. They only make conclusions based on uncontrolled experiments (Osterhaus et al., 2020).

The intermediate level of reasoning lies between the naïve and the advanced levels. The children exhibit an emerging metaconceptual understanding of explaining facts and systematic Expt not yet fully explicit. Learners with this form of reasoning believe that scientists conduct an experiment to obtain simple data that serves as the basis for making conclusions (Koerber et al., 2015; Kuhn, 2010). However, they only make use of simple data.

The advanced level of reasoning is the highest level (Koerber et al., 2015; Kuhn, 2010; Osterhaus et al., 2020). Learners at this level believe scientists test various assumptions and hypotheses through controlled experiments. Thus, scientists conduct systematic experiments on identified problems to obtain appropriate data. Based on the experiments' data, scientists can make valid interpretations of complex and challenging data patterns (Koerber et al., 2015; Kuhn, 2010). Attainment of the advanced level of reasoning has been the focus of science education. This is because it is at this level that learners are able to critically examine issues and make informed decisions. Such abilities do not just exist during their schooling days but stay with them throughout their lifetime.

Muslu Kaygisiz et al. (2018) accentuated that the growth and development of scientific reasoning skills is tied to age and class (grade) levels. As pupils grow older and progress through grade levels, their cognitive abilities naturally mature. That is, pupils become better equipped to think abstractly, critically, and logically. These cognitive developments enable them to engage in more complex scientific reasoning tasks. With each passing year of education, pupils accumulate more knowledge and exposure to scientific concepts (Korom et al., 2017). This growing knowledge base provides them with a foundation upon which they can build more advanced reasoning skills. Korom et al. (2017) added that as pupils move up the grade levels, they typically receive more extensive exposure to scientific principles, theories, and methodologies. This exposure allows them to practice and apply their reasoning skills in various scientific contexts. Educational curricula are often designed to scaffold students' learning experiences. In other words, the curriculum is structured to introduce and reinforce scientific reasoning skills in a sequential manner (Alemu et al., 2017; Osterhaus et al., 2020). Each grade level may build upon the skills developed in the previous one, gradually increasing the complexity of tasks and challenges.

Different authors have sought to identify the level of scientific reasoning of learners. In Germany, Osterhaus et al. (2020) assessed the level of reasoning skills of 1,353 grade three pupils and concluded that primary school pupils demonstrated naïve reasoning skills. A similar study was conducted by Zulkipli et al. (2020) in Malaysia revealed that students demonstrated low (naïve) scientific reasoning skills. Likewise, Schiefer et al. (2019) assessed the reasoning skills of grade 3 and grade 4 elementary (primary) school children and observed that although grade 3 and grade 4 elementary school children were able to show scientific reasoning activities, they were operating at the naïve (low) level. Kambeyo (2018) also reported that in Namibia, students demonstrate low (naïve) scientific reasoning skills.

Sex Differences in Scientific Reasoning Skills

Literature is replete with empirical research comparing the reasoning skills of boys and girls at all levels of education. Some scholars believe no major difference exists in scientific reasoning between boys and girls and others claim otherwise. For instance, Koerber et al. (2015) compared the reasoning skills of boys and girls in second, third, and fourth grades in elementary schools in Germany. The results of the study indicated boys and girls demonstrated similar reasoning abilities. Similar findings were obtained by Korom et al. (2017) in the scientific reasoning skills of boys and girls in grade four in Finland. In higher grade levels, Kambeyo (2018) accentuated that boys and girls in 5th and 7th grades exhibited similar scientific reasoning skills in Namibia. Despite the fact that Amoah and Eshun (2018) assessed the reasoning skills of senior high school students in Ghana, the reasoning skills of boys did not differ significantly from girls.

On the other hand, the findings of Johnson (2001), Valanides (1996), and Yang (2004) showed that a difference exists in the reasoning skills of boys and girls. For instance, Johnson (2001) assessed the scientific reasoning skills of young adults and found that a significant difference exists in the mean score of boys and girls in scientific reasoning with the girls performing relatively better than the boys. However, Yang (2004) found that a significant difference existed in the scientific reasoning skills of boys and girls in favour of boys. This finding was supported by Valanides (1996), who discovered that boys performed relatively better in scientific reasoning tasks than girls. The findings are similar to the assertion of Kuhn and Holling (2009), who opined that sex has an influence on scientific reasoning skills and the general performance of young adults in higher levels of education.

The evidence points to an inclusive situation when it comes to sex differences in scientific reasoning. While some studies did not notice any difference in scientific reasoning between boys and girls, other studies identified a difference. The situation becomes blurrier since there is no consensus as to which of the sexes performs better in scientific reasoning skills. This creates an avenue for further exploration of scientific reasoning skills pertaining to boys and girls in our educational systems in order to devise appropriate remedial actions so as not to leave any child behind.

METHODOLOGY

Research Design

This study employed a cross-sectional survey design (Cohen et al., 2007; Creswell, 2014) to assess the scientific reasoning skills of primary school pupils in Ghana. The use of the cross-sectional survey enabled the collection of information to describe the scientific reasoning skills of primary school pupils at a particular time (Cohen et al., 2007). The design helped bring to light the scientific reasoning skills of different primary school pupils at different class levels from the Ghanaian population to address questions related to their scientific reasoning skills and test whether any difference exists in the reasoning skills of boys and girls in different class levels.

Participants

To obtain participants for the study, 10 primary schools from Kumasi Metropolis in the Ashanti Region of Ghana were randomly selected using computer-generated numbers. In each school, three classes of grades 4, 5, and 6 were selected for the study. Eight of the ten sampled schools had more than one class for each grade level, and in such a situation, one class in each grade level was randomly sampled using computer-generated numbers. This was done to give equal opportunity to every child in each class level in the selected school to take part in study. The learners in selected classes constituted sample for study. In all, 1,066 primary school pupils were used for the study, with 332 (31.1%) class 4 pupils, 357 (33.5%) class 5 pupils, and 377 (35.4) class 6 pupils. In class 4, there were 164 (49.4%) boys and 168 (50.6%) girls. In class 5 there were 169 (47.3%) boys and 188 (52.7%) girls. Lastly, there were 180 (47.7%) boys and 197 (52.3%) girls in class 6.

Instrument

Science P reasoning inventory (SPR-I) (Osterhaus et al., 2020) was adapted to assess the scientific reasoning skills of primary school children in Ghana. SPR-I is an instrument developed to assess primary school children's scientific reasoning skills. SPR-I consists of 23 multiple-choice items that assess the scientific reasoning skills of primary-school pupils in three sub-constructs (NoS, Expt, and DI) within scientific reasoning skills. The culmination of the sub-constructs produces effective scientific reasoning. A student lacking in any of the sub-constructs will have defective scientific reasoning holistically. NoS construct was assessed with eleven items, Expt construct was assessed with six items and DI construct was assessed with six items. In all the items in the inventory, pupils were presented with three response options for each item. The instrument was adapted because some of the words on the instrument were not familiar in the Ghanaian context and others were advanced for the primary school pupils in Ghana. Hence, these words were changed and rephrased into words that Ghanaian primary school pupils would understand. For instance, words like "imps", "grade," and "middle ages," which are not common to Ghanaian primary school children, were changed to "dwarfs", "class," and "olden days," respectively. Again, words like "invent" and "brew" were changed to "make" and "made," respectively.

The items on the inventory were scored on a 3-credit scale of 0, 1, and 2, with the score indicating the three levels of scientific reasoning: naïve, intermediate and advanced level of reasoning. Pupils who chose the naïve answer (regardless of their agreement with the other levels) or reject all answer choices were scored as SPR-I (0). Pupils who chose the intermediate but not the advanced level received partial credit (intermediate level, 1), and only those who chose the advanced but refused all other stages received full credit (advanced level, 2) (Osterhaus et al., 2020). Pupils were directed to attempt all items on the inventory.

Pilot Testing

The adapted SPR-I instrument was pilot-tested within four schools in the Cape Coast Metropolis in the Central Region of Ghana. The Cape Coast Metropolis was used for the pilot study because it is one of the metropolises in the country with similar characteristics to the sampled schools of the study. The instrument was pilot-tested to explore how the subjects were going to "experience and understand" items on the instruments to enable the researcher to fine-tune certain items on the instrument to obtain consistent results. Besides, because the instrument was new in the Ghanaian context, a pilot study was deemed important to ensure that the language and terms used in the research instruments were easy to understand. The internal consistency of the items on the instrument was determined with the Cronbach's alpha reliability coefficient. The instrument had a reliability of 0.7. After the final data, the reliability of the instrument was again determined with Cronbach's alpha. Hence, the instrument was found to be internally consistent and appropriate for collecting information on the scientific reasoning skills of Ghanaian primary school pupils (Cohen et al., 2017). None of the items on the instrument were deleted after the pilot study; however, some of the items that pupils demonstrated difficulty in understanding were rephrased into words that primary school pupils understood.

Data Collection Procedure

Ethical clearance was sought from the University of Cape Coast Institutional Review Board. Permission was sought from the directorate of education in the Kumasi Metropolis. Since most of the children were under 18, parental consent was sought to allow their children to participate in the study. The study was explained to the children and their explicit consent was sought. The children were assured of confidentiality and anonymity of their responses. The researcher interacted with the pupils on the first day of data collection to familiarize them with the children and prepare them psychologically for the study. On the second day of data collection, SPR-I instrument was administered to the learners early in the morning. The items on the instrument were read to the learners after which they selected their responses. The items were read because Osterhaus et al. (2020) recommend that items on SPR-I instrument should be read to learners of younger age such as those in primary schools. The inventory was collected after the process. Approximately 90 minutes were used to complete the process in each class.

Data Analysis

The level of scientific reasoning skills of primary school pupils was measured by determining the means and standard deviation (SD) of their responses. Primary school pupils were then classified into naïve, intermediate and advanced levels of scientific reasoning based on their

Table 1. Primary school pupils' scientific reasoning skills mean

Class	n	Mean	SD
Class 4	332	0.54	0.22
Class 5	357	0.63	0.24
Class 6	377	0.72	0.29

Note. SD: Standard deviation

mean value. Since the items on the inventory were scored on a 3-credit scale of 0, 1, and 2, indicating pupils' level of reasoning (naïve, intermediate, and advanced), equal intervals were used. Since the scoring was categorical in nature, but the mean scores were continuous, it was necessary to recalibrate the scale to cater for intermediate scores to make the interpretation of the scores consistent. Therefore, a mean range of 0.00-0.67 was considered a naïve level of reasoning, a mean range of 0.68-1.34 was considered an intermediate level of reasoning and that of 1.35-2.00 was classified as an advanced level of reasoning for interpretation purposes. Each interval represented a consistent increase in reasoning skills by 0.67 points. In other words, by assigning equal intervals of 0.67 to each category, the scale guarantees that every step represents a uniform and quantifiable progression in the reasoning abilities of primary school pupils (Alabi & Jelili, 2023). This allowed for an objective and uniform assessment of pupils' scientific reasoning skills, making it easier to interpret and compare their scores. The difference in scientific reasoning between boys and girls for various class levels was analyzed with an independent sample t-test. The assumptions of "normality, linearity and homogeneity" of variance were tested (Pallant, 2010). The significant level of Levene's test was 0.867, suggesting that the variance between the two groups is significantly similar. This shows that the assumption of equal variances was not violated (Pallant, 2010). With respect to the normality, the Shapiro-Wilk test revealed a p-value less than 0.05, suggesting that the dependent variable (scientific reasoning skills) was not normally distributed. This prompted the need for data transformation to meet the fundamental assumption of normality (Manikandan, 2010). Since the histogram of the data indicated a slightly rightly skewed, a Box-Cox transformation was applied as it optimally adjusted the data to approximate a normal distribution. This allowed for the use of various statistical techniques that assume data normality, ultimately enhancing the validity and interpretability of the analysis results (Manikandan, 2010). Multivariate analysis of variance (MANOVA) was employed to examine how pupils' scientific reasoning skills in different sub-constructs, as captured in the instrument, varied in each class level. Preliminary analysis of the data demonstrated no violation of all assumptions of MANOVA for multicollinearity and linearity, homogeneity of covariance matrices, multivariate outliers, and test of equality of error variance.

RESULTS

In general, primary school pupils in grade 4 and grade 5 demonstrated naïve scientific reasoning skills, and those in class 6 demonstrated an intermediate level of scientific reasoning skills. This was because the mean scientific reasoning skills on all items on SPR-I instrument were 0.54 (SD=0.22), 0.63 (SD=0.24), and 0.72 (SD=0.29) for grades 4, 5, and 6, respectively, as shown in **Table 1**.

In terms of the various sub-constructs within scientific reasoning, pupils in classes 4 and 5 exhibited naïve scientific reasoning skills with

Table 2. Primary school pupils scientific reasoning skills in each sub-construct

Sub-constructs	Class	n	Mean	SD
NoS	Class 4	332	0.59	0.27
	Class 5	357	0.63	0.32
	Class 6	377	0.74	0.33
Expt	Class 4	332	0.54	0.32
	Class 5	357	0.63	0.30
	Class 6	377	0.67	0.39
DI	Class 4	332	0.47	0.33
	Class 5	357	0.64	0.34
	Class 6	377	0.73	0.37

Note. SD: Standard deviation; NoS: Nature of science; Expt: Experimentation; & DI: Data interpretation

a mean score of 0.59 (SD=0.27) and 0.63 (SD=0.32), respectively, whilst those in class 6 exhibited an intermediate level of reasoning abilities in NoS constructs (**Table 2**). For Expt sub-construct, classes 4, 5, and 6 pupils demonstrated naïve scientific reasoning skills with a mean score of 0.54 (SD=0.32), 0.63 (SD=0.30), and 0.67 (SD=0.39), respectively. Regarding DI sub-construct, class 4 and class 5 pupils demonstrated naïve reasoning skills with a mean score of 0.47 (SD=0.34) and 0.64 (SD=0.35) while class 6 pupils exhibited intermediate reasoning skills, with a mean score of 0.73 (SD=0.37).

The second objective sought to find out whether any statistically significant difference exists in the scientific reasoning skills between boys and girls in each class level. In this objective, there were two folds of analysis. Firstly, an independent sample t-test was conducted to compare the mean score of the scientific reasoning skills of boys with that of girls in each class and the second part compared boys and girls in each class on the various sub-constructs. The results in **Table 3** indicate that there was no statistically significant difference between boys (mean [M]=0.54, SD=0.21) and girls (M=0.55, SD=0.23, t[330]=.-312, p=.755) in class 4 in their scientific reasoning skills. In class 5, there was no statistically significant difference between boys (M=0.63, SD=0.26) and girls (M=0.63, SD=0.23, t[355]=.-031, p=.976), with all of them demonstrating naïve scientific reasoning skills. In class 6, all of them demonstrated intermediate scientific reasoning skills with no statistically significant difference between boys (M=0.73, SD=0.30) and girls (M=0.70, SD=0.28, t[375]=1.006, p=.315).

Concerning the difference in scientific reasoning skills of boys and girls in each class in the various sub-constructs, one-way MANOVA was conducted (**Table 4**). The pupils' scores in scientific reasoning sub-constructs (NoS, Expt, and DI) were the dependent variables. The independent variable was the pupils' sex in each class level. There was no statistically significant difference in mean scores between boys and girls in class 4 on the sub-constructs of scientific reasoning skills (F[3, 328]=1.419, p=0.237, Pillai's trace=0.013). This implies that boys and girls in class 4 demonstrate similar reasoning skills in NoS, Expt, and DI. A similar observation was recorded in class 5; there was no statistically significant difference in mean scores between boys and girls on the sub-constructs of scientific reasoning skills (F[3, 353]=2.171, p=0.091, Pillai's trace=0.018). Again, in class 6, there was no statistically significant difference in mean scores between boys and girls on the sub-constructs of scientific reasoning skills (F[3, 373]=.528, p=0.663, Pillai's trace=0.004). The results implied that boys and girls in classes 4, 5, and 6 pupils demonstrated similar reasoning skills in the various sub-constructs in scientific reasoning skills.

Table 3. Independent sample t-test results for scientific reasoning between boys & girls

Variable	Class	Sex	n	Mean	SD	t	df	p
Scientific reasoning skills	Class 4	Boys	164	0.54	0.21	-.312	330	.755
		Girls	168	0.55	0.23			
	Class 5	Boys	169	0.63	0.26	-.031	355	.976
		Girls	188	0.63	0.23			
	Class 6	Boys	180	0.73	0.30	1.006	375	.315
		Girls	197	0.70	0.28			

Note. SD: Standard deviation

Table 4. Summary of MANOVA results on scientific reasoning skills of boys & girls in various sub-constructs

Class	Dependent variable	Multivariate F	Pillai's trace	df	p	Partial eta squared
Class 4	Nature of science					
	Experimentation	1.419	.013	3,328	0.237	.013
	Data interpretation					
Class 5	Nature of science	2.171	.018	3,353	0.091	0.018
	Experimentation					
	Data interpretation					
Class 6	Nature of science					
	Experimentation	.528	.004	3,373	0.663	0.004
	Data interpretation					

DISCUSSION

The results of the study demonstrated that class 6 pupils had the highest level (intermediate) of scientific reasoning skills as compared to class 4 and class 5 pupils, who showed naïve reasoning skills based on their mean scores. This result is reflected across the various sub-constructs in scientific reasoning skills with class 4 and class 5 pupils demonstrating naïve reasoning skills in all the sub-constructs whilst class 6 pupils showed intermediate reasoning skills in all the sub-constructs. The fact that class 4 and class 5 pupils consistently demonstrated naïve reasoning skills in all sub-constructs, while class 6 pupils consistently showed intermediate reasoning skills, underscores the robustness of the observed trend. The findings unravel the developmental progression in scientific reasoning skills among primary school pupils The results indicate that as pupils proceed from class 4 and class 5 to class 6, there is an observable improvement in their scientific reasoning abilities. This aligns with the expectation that pupils should acquire higher cognitive skills as they progress through their education. This finding is in tandem with the findings of Alemu et al. (2017) and Muslu Kaygisiz et al. (2018) who reported that the growth and development of scientific reasoning skills is tied to class (grade) levels. Thus, scientific reasoning skills develop with increasing class levels. Moreover, Korom et al. (2017) concluded in their study that scientific reasoning skills develop as students progress on the academic ladder.

Although it is typically expected that as pupils progress through different grade levels, they would exhibit a gradual improvement in their reasoning skills (Osterhaus et al., 2020), the findings of this research show that both class 4 and class 5 pupils displayed similar reasoning skills (naïve). This suggests a potential delay or stagnation in the reasoning skills of class 5 pupils or an improved reasoning of class 4 pupils. Whatever the situation may be, it is worth investigating further. Understanding why pupils in these classes are not demonstrating the expected differences in their reasoning skills is crucial for addressing their educational needs. Such exploration will determine the necessary remediation needed to be put in place for students who are operating at a lower level.

The study also found no statistically significant difference in scientific reasoning between boys and girls in the respective classes. Boys and girls in both class 4 and class 5 demonstrated similar reasoning skills (naïve) and boys and girls in class 6 demonstrated similar reasoning skills (intermediate). The results also indicate that within each class level, there were no significant differences in scientific reasoning skills between boys and girls across various sub-constructs. This indicates that sex had little to no influence on pupils' scientific reasoning skills across the three grade levels examined. This implies a positive outcome for gender equity in science education. That is, both boys and girls in these classes had relatively equal opportunities to develop and demonstrate their scientific reasoning abilities. The finding is supported by Koerber et al. (2015), who also found no difference in the scientific reasoning skills of boys and girls in elementary (primary) schools in Germany. Korom et al. (2017) observed in their study that the scientific reasoning abilities of grade (class) four children were not affected by their sex.

The finding of no difference in scientific reasoning skills between boys and girls in primary schools in Ghana could be due to the fact that young age of the population used for the study. In older children, sex has been shown to influence scientific reasoning skills and the general performance of students (Kuhn & Holling, 2009). Again, no difference in scientific reasoning between boys and girls could be due to the fact that boys and girls receive equal classroom activities that focus on the content of science to the neglect of scientific reasoning skills.

CONCLUSIONS & RECOMMENDATIONS

The study's findings provide valuable insights into the developmental progression of scientific reasoning skills among primary school pupils and the influence of gender on these skills. The study demonstrates a clear developmental trend in scientific reasoning skills, with class 6 pupils exhibiting higher (intermediate) reasoning skills compared to class 5 and class 4 pupils who displayed lower (naïve) reasoning abilities. However, the unexpected discovery that both class 4 and class 5 pupils exhibited the same level of reasoning skills (naïve) raises questions and suggests the need for further investigation into the causes of this outcome. Potential factors could include the curriculum, teaching methods, or individual differences among students. The study's findings highlight the need for a carefully structured and progressive curriculum that effectively develops scientific reasoning skills as students advance through grade levels. It must be pointed out that if primary school pupils in Ghana, especially those in class 4 and class 5, continue to demonstrate a low level of scientific reasoning skills, it will have a negative rippling effect on the study of science and general performance at the higher levels of education. It is, therefore, recommended that the development of Ghanaian primary school pupils' scientific reasoning skills should be factored into classroom activities in order to develop their reasoning. That is, educators should critically assess their teaching methods and instructional strategies to ensure they promote the development of scientific reasoning skills. Curriculum designers should consider incorporating specific modules or lessons aimed at enhancing these skills to ensure a smooth transition from naïve to advanced levels. The unexpected similarity in reasoning skills between class 4 and class 5 suggests that teaching approaches may need adjustments to better align with the desired educational outcomes. The study's findings provide strong evidence of gender equity in science education among primary school pupils in classes 4, 5, and 6. Both boys and girls demonstrated similar scientific reasoning skills, dispelling any significant gender-based differences. This has important implications for promoting equal opportunities and inclusivity in science learning. Educators and policymakers should use these results to encourage active participation of both boys and girls in science education

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