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Assessing Students' Understanding of Control of Variables across Three Grade Levels and Gender

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Abstract

Research studies that deal with student ability to investigate and carry out inquiry oriented investigations often call for educational practitioners to pay particular attention to incorporating the skills of scientific inquiry in the process of teaching and learning. This has the aim of helping learners acquire the skills needed to become problem solvers and independent thinkers. One aspect of the inquiry practice that is directly related to student ability to carry out scientific investigations is the ability to handle and control experimental variables. This skill is commonly known as 'control of variables ability'. Control of variables, as a process skill, has been widely regarded as an important ability in scientific investigations. The purpose of this study, therefore, was to assess how well students across educational grade levels develop this important process skill. Specifically, this study was designed to assess the understanding of the control of variables of selected sample of science students from grades 8, 10, and 12 and to compare these students in relation to the development of this ability across grade levels. Using an assessment framework developed and used by the American Association for the Advancement of Science (AAAS), 128 science students were tested to assess their understanding of ideas pertaining to control of variables as a fundamental integrated process skill. The findings revealed that students across grade levels exhibited alternative conceptions of key ideas related to control of variables as a fundamental ability such as testing hypotheses, selecting the appropriate experimental setup, handling more than two variables, and providing valid explanations to the expected outcomes of an experimental setup. These findings suggested that much work is needed to improve student ability to handle and control experimental variables particularly in the context of UAE Curriculum and recent educational reforms that stress the need for better preparation of students to meet the challenges of today's changing societies. The findings have also highlighted that such a need for better preparation of students for the future scientific inquiries requires new curricula and teaching approaches that respond to and focus on not only learning essential scientific content but also on acquiring advanced transferable abilities related to scientific inquiry and logical reasoning skills that can be used to solve societal problems.

Keywords: control of variables, scientific inquiry, misconception, UAE curriculum, science process skills

1. Introduction

1.1 Background

Research studies that deal with students' ability to investigate and carry out inquiry oriented investigations often call for educators and teachers to strive toward incorporating scientific inquiry in the process of teaching and learning, to help learners acquire skills needed to become problem solvers and independent thinkers (Arnold, Kremer, & Mayer, 2014; Hume & Coll, 2010; Kuhn, 2002; National Research Council, 1996; Zimmerman, 2007). The call for such incorporation was necessitated by the explicit focus of almost all science curricular around the world on the importance of, and the need for instilling such abilities in students. One aspect of the inquiry practice that directly related to student ability to carry out inquiry oriented investigations is the ability to handle and control experimental variables. Control of variables as a fundamental science process skill has been widely regarded as an important ability in scientific investigations and as an integral component of most curricular around the world. This skill provides students with the scope and understanding needed to carry out controlled and reliable experiments that might eventually lead to trusted outcomes and valid inferences (Chen and Klahr, 1999). As such, most science curricular around the world devotes much time to the development of this skill. This is achieved through the implementation of activities in science education to help students acquire the necessary skills of controlling variables as well as other advanced skills to progress in their inquiry oriented learning. Additionally, teachers were highly encouraged to adopt approaches that provide students with opportunity to participate in scientific thinking such as manipulating and controlling experimental variables (Boudreaux, Shaffer, Heron, & McDermott, 2008; Keselman, 2003).

Despite the compelling evidence of the importance of the control of variables as a needed process skill, there are few studies that deal with how students approach and eventually develop the understanding of control of variables. Research studies call for critical investigations to suggest and develop methods and approaches needed to help students develop sound and coherent understanding of this crucial and essential skill (Gogos & DeBoer, 2007). Some of the difficulties in understanding the skill of control of variables were found to be conceptual rather than procedural as Gogos and DeBoer (2007) suggested. In their study, Gogos and DeBoer (2007) found that "students often use ideas about the physical situation being described rather than drawing on the idea that only one variable should vary while all others are kept constant" (p. 1). Other studies (Chen & Klahr, 1999; Keselman, 2003; Park & Pak, 1997) suggested that students encounter difficulties with procedural knowledge as well as conceptual knowledge when engaged with control of variables activities. The findings from these studies suggested that the concept of the control of variables proved to be difficult for most students. Keselman (2003) found that students were unable to recognize the fact that several variables can contribute to an experimental result. On the other hand, Chen and Klahr (1999), unlike Gogos and DeBoer (2007) suggested that control of variables could be considered both procedural and logical understanding. Procedural understanding is the ability to manipulate variables to construct and produce an understanding of how and why things behave or exist the way they are. For example, Roberts and Gott (2003) explained this as knowledge of concepts associated with validity, reliability and generalizability. As a logical understanding, it is the ability to develop and construct appropriate conclusions from an experiment that are valid, trusted, and plausible. As such, this skill is challenging to students as it consists of both procedural and logical understanding. The procedural and logical aspects of the control of variables were also investigated by Park and Pak (1997) who found that students had difficulty recognizing when the available evidence is not sufficient to decide on how much the manipulated variable or variables impacted the dependent variable. A similar study by Boudreaux, Shaffer, Heron, and McDermott (2008) found that, although most of the students participating in their study were able to realize the importance of having controlled conditions for experimentation, many students had difficulties in providing valid justification for why controlled conditions were important. These findings suggest noticeable shortcomings and implications for the preparation of these students and their future as scientifically literate citizens.

The complexities surrounding understanding of the concept of control of variables extend to science teachers. In an early study, Shadmi (1981) studied science teachers' understanding of the control of variables and found that most teachers had difficulty interpreting the results in the context of experimental settings. They often could not explain whether a particular variable influenced or determined the results of the experiment.

Although findings from previous research studies suggested difficulties with understanding the concept of control of variables, studies that investigated intervention programs designed to improve student understanding were relatively successful in positively influencing the development of the control of variable among students. For example, Keselman (2003) described an intervention strategy based on computer software designed to facilitate and enhance understanding of multivariable causality. Keselman was able to present evidence of increased attention among participants and also a tendency towards the use of systematic strategies to link cause and effect. Furthermore, Keselman (2003) found that students who were taught, explicitly, how to make scientific predictions were significantly better in the use of multiple comparative strategies to construct inferences. This suggests that students have developed the skill of control of variables. Similar results were reported by Boudreaux, Shaffer, Heron, and McDermott (2008) where teachers who had been guided to use reasoning process over an extended period of time had significantly improved not only in the reasoning but also in "confidence to do, learn, and teach science" (p. 169).

In recent years, science education within the United Arab Emirates (UAE) has undergone numerous reform initiatives in line with policy makers' aspirations and vision. Most of these initiatives have emphasized the necessity of students to develop inquiry related skills through their actual involvement in investigative activities such as those that require control of variables. At the core of recent education initiatives is the focus on developing students' problem-solving and analytical skills to equip them with the competencies that they need to succeed in the future and to become independent thinkers and problem solvers who can contribute positively to social and economic development of the country. For example, Abu Dhabi Education Council (ADEC) has recently introduced what is commonly known as "*New School Model*- NSM", a model that is based on a student-centered learning environment, where students learn in a well-resourced and technology-rich environment, to foster a child-centered learning approach, develop critical thinking, and cultural and national identity. Within this model the teaching learning processes are directed to enhance student development and learning as communicators, critical thinkers, and problem solvers (ADEC, 2014). In line with ADEC philosophy, it becomes important to provide students with the right balance of content and skills to achieve the goals stated for education and learning processes. Balancing scientific content with scientific skills, such as the ability to manipulate variables requires understanding of the perspectives of controlled experimentations and independent thinking about scientific phenomena. Control of variables is therefore an essential process skill that could help learners understand and develop scientific knowledge and scientific thinking. Kuhn and Dean (2005) explained the importance of the control of variables as a skill related to the thinking process in a much broader view. They argued on the importance of the control of variables as an essential component of reasoning skills, not only required to develop the techniques of controlling variables but also to recognize the contribution of each individual variable independently through manipulation and control of individual variable effect (Kuhn & Dean, 2005). Following the vein of considering control of variables as a fundamental process skill underlying the practice and execution of trusted experiments, and the significant emphasis placed on the value of problem solving and analytical and reasoning skills by the UAE educators, it becomes imperative to assess the status of such an important skill among UAE students.

1.2 Purpose

The main concern of this study was to document students' understanding of ideas related to the control of variables as a complex and integrated science process. The purpose of this study was, therefore, to assess the understanding of the control of variables of a selected sample of grade 8, 10, and 12 science students and to compare their performance in relation to the development of this ability across grade levels and student gender. Control of variables, as an important skill needed for scientific investigations has been extensively studied and documented. However, in the context of United Arab Emirates (UAE) no previous studies were conducted to examine student' understanding of this skill. From this perspective, the findings of this study may be regarded as a unique addition to the UAE knowledge base and its science education literature. Furthermore, the findings may help seek understanding of how students develop this fundamental skill as they progress through the official curriculum as well as shedding light on the expectations stated in the curriculum which focus on development of students' abilities to reason and use evidence based reasoning to solve everyday problems.

2. Method

2.1 Context

This study was conducted at public schools of Abu Dhabi Education Council (ADEC), the education agent responsible for managing and running general education in the Emirate of Abu Dhabi. Since its establishment as an administrative body tasked with running the education system of the Emirate of Abu Dhabi, ADEC has continued to introduce new initiatives to foster and further develop school curriculum. Among the recent initiatives introduced are those related to teaching and learning such as "New School Model- NSM", bilingual instruction where both Arabic as the national language and English are emphasized, as well as organization of curriculum along educational cycles. Within these structural changes, more emphasis was placed on the role of the learners as active participants in an inquiry oriented instruction where the role of reasoning, critical thinking and problem solving are emphasized. Within the NSM, students are required to work together to engage in investigating problems, ask scientific questions, analyze, reason and think critically about the context of their investigation. It is within this context that this study was conducted.

2.2 Participants

A total of 128 students selected from 6 schools from grade 8 (age 13-14), grade 10 (age 15-16), and grade 12 (age 17-18) represented the sample of this study, with 66 females and 62 males, including 35 students in grade 8, 44 students in grade 10 and 49 students in grade 12. Students in all schools run by ADEC follow the same curriculum in which science and mathematics are regarded as core and compulsory subjects studied in Cycle 2 and 3. The classes representing the sample were selected randomly from a convenience population of schools within ADEC's educational zones. Grades 8, 10, 12 were chosen for various reasons. Grades 8, 10 and 12 represent all levels for educational cycles used by ADEC (Cycle 2 which covers grades 6-9 and Cycle 3 which covers grades 10-12). Grade 10, on the other hand is the level at which students start streaming into science and arts streams and therefore it is critical to study those students who optionally choose to continue studying science. Furthermore, previous research findings suggest that student ability to understand and apply reasoning associated with control of variables might undergo noticeable changes during the transition from preparatory level through senior secondary level (Chen & Klahr, 1999) which may allow comparative analyses as to the nature and characteristics of thinking associated with the control of variables. These grade levels were therefore regarded as suitable for assessing terminal learning outcomes.

2.3 Instrument

The study employed an assessment of control of variable technique developed by the American Association for the Advancement of Science (AAAS, 2012). The AAAS developed a long term initiative that focuses on developing and testing scientific literacy through high-quality and reliable test items covering a wide range of scientific literacy. Items related to control of variables were rigorously developed and aligned to national standards which can be used with diverse ranges of students including students such as those participated in this study.

The present study explored 4 sub-ideas related to the control of variables, namely testing hypotheses, selecting the appropriate experimental setup, handling more than two variables, and providing valid explanations to the expected outcomes of an experimental setup. The conceptual level of understanding expected from students for each sub-idea as described by the AAAS (2012) is as follows:

Testing of hypothesis if given an idea to be tested: Ability to test hypothesis if given an idea in a given context that requires an experimental setup and manipulation of variables, and explain why some of the variables must be manipulated in order to isolate their effect on another variable that is not manipulated.

Selecting appropriate experimental setup: Ability to develop appropriate experimental system to assess the influence of a variable (as independent) on the another variable (as dependent) taking into account the influence of other independent variables through control and management. Developing appropriate experimental system also entails understanding that changing more than variable at the same setup will not lead to understanding of the effect of any of the independent variables.

Handling more than two variables: Ability to recognize that when manipulating more than one variable at the same experimental setup no valid conclusions can be drawn from the experimental setup

Providing valid explanations: Ability to determine and develop valid argumentations and explanations when given experimental outcomes (AAAS, 2012).

Each sub-idea was tested using appropriate item form the bank of questions developed by AAAS. As such, an 8-item test was developed and modified to suit the context of the study. The modifications introduced to the selected items included transforming the items into two tier items instead of the original multiple choice format. Two-tier format often includes in addition to the traditional multiple-choice questions, a second tier that requires justification or reasoning regarding the answer chosen for the multiple-choice question. The control of variable is a concept that requires explicit reasoning and justification on what variable(s) should be manipulated and what variable(s) should be kept constant. Recent studies (Arnold, Kremer and Mayer, 2014; Hume and Coll, 2010; Zimmerman, 2008) discussed the relationship between the conceptual understanding and the scientific reasoning of a particular conceptual knowledge- suggesting an association between ability to reason and to undertake inquiry related practices.

Two-tier instruments were used extensively in the literature and were found to be highly effective in assessing students' understanding of scientific concepts and processes (António, Clévio, Isabel, & Celeste, 2012; Artdej, Ratanaroutai, Coll, & Thongpanchang, 2010; Haslam &Treagust, 1987; Lin, 2004; Peterson & Treagust, 1989). Two-tier items are therefore thought of as better reflecting the conceptual understanding of the concept "control of variables", identify thinking possessed by participants, and, pinpoint further any alternative understandings exhibited by participants.

The second modification of the chosen items is the translation of the selected items into Arabic, the language of the participants to remove any influences that the language factor that might have and interfere with their understanding of the concept.

Following the addition of the second tier and the translation, the new version of the items were subjected to validation processes. The initial steps of test content and construct validation were employed to make sure that the items measure what are supposed to measure in terms of language difficulty (translated version) and appropriateness for the sample. Feedback received from the validation process such as rewording some of the newly developed second tier was incorporated by rewording some of the questions identified as not appropriate. The Flesch–Kincaid grade level readability was calculated using online software and was found to be 6.7 with a reading ease of 80, indicating that the questions have an appropriate readability level for the participants. Cronbach alpha reliability calculated for the whole sample was found to be 0.63 which was deemed to be suitable for the study. Table 1 shows the final version of the test items. Sample items were shown in Appendix A. The test was administered to students at their normal classes under the supervision of their class teachers.

Table 1. Final version of test items

Sub-idea tested	Question
Testing hypothesis if given an idea to be tested in a given context	1 and 2
Selecting appropriate experimental setup	3 and 4
Handling more than two variables	5 and 6
Providing valid explanations to experimental setup	7 and 8

Data collected were analyzed for level of understanding as well as for any alternative understandings revealed by the two-tier format. Student responses for each question were regarded as correct if the student answers both tiers correctly. Frequencies and percentage of student responses were calculated for each question. Gender analysis was carried out in a similar way.

3. Results

3.1 Understanding of Control of Variables across Grade Levels

Analysis of student responses to the test questions were presented in Tables 2- 5. The four sub-ideas related to the understanding of control of variables (ability to test hypothesis, select experimental setup, handling more than two variables, and ability to provide valid explanation) were found to be progressing with grade levels. As students progressed through grades (from 8 to 12) their understanding improved as reflected by the percentages of students who correctly responded to the questions.

Trends depicted in Table 2 indicated that students struggled with the reasoning process. Table 2 presents frequencies and percentages of the whole sample to questions. Percentages of students who correctly identify the right answers together with the appropriate justification ranged between 12.5% for question 7 and 28.1% for question 3, indicating low level of reasoning ability compared to percentages of students who correctly chose the first-tier only. First-tier only correct responses ranged between 35.2% for question 8 and 60.9% for question 2.

Table 2. Frequencies and percentage of student responses to the test questions

	Two-tier correct	First-tier correct
1	33 (25.8%)	64(50.0%)
2	22 (17.2%)	78 (60.9%)
3	36 (28.1%)	50 (39.1%)
4	32(25.0%)	59 (46.1%)
5	22 (17.2%)	62 (48.4%)
6	20 (15.6%)	72 (56.3%)
7	16 (12.5%)	59 (46.1%)
8	25 (19.5%)	45 (35.2%)

Although the percentage of students who showed understanding of the concept of “control of variables” represents less than two-third of the sample, it is still fair better than the percentage of students when considering the two-tiers of the test.

Table 3 shows that for item 1 only 14.3%, 22.7%, and 34.7% of students in grades 8, 10, and 12 respectively managed to correctly provide correct answers and were able to justify these answers. The same trends were shown in the rest of the items. Comparing the correct responses for the two tiers of the test the findings revealed that there was an increase in performance as students progressed through grade levels which is an indicative of how students benefited from the curriculum. For example, the understanding of students, in Grade 8 improved from 17.3% to 59.2% in grade 12 regarding the ability to test hypotheses if given ideas to be tested. For ability to select appropriate experimental setup (item 3 and 4), students' performance had also improved from 28.5% in grade 8 to 69.4% in grade 12. The lowest increment was found to be related to ability to explain experimental setup (items 7 and 8). These findings suggest that although there was an increase in performance of students from grade to another, the nature of the increment does not seem be the same for the tested sub-ideas.

Table 3. Frequencies and percentage of student responses to the test questions

Question	Grade 8		Grade 10		Grade 12	
	Two-tier correct	First-tier correct	Two-tier correct	First-tier correct	Two-tier correct	First-tier correct
1	5 (14.3%)	17 (48.6%)	10 (22.7%)	17 (38.6%)	17 (34.7%)	30 (61.2%)
2	1 (3.00%)	23 (65.7%)	9 (20.5%)	25 (56.8%)	12 (24.5%)	30 (61.2%)
3	6 (17.1%)	8 (22.9%)	15 (34.1%)	18 (40.9%)	15 (30.6%)	24 (49.0%)
4	4 (11.4%)	14 (40.0%)	9 (20.5%)	26 (59.1%)	19 (38.8%)	19 (38.8%)
5	3 (8.6%)	20 (57.1%)	9 (20.5%)	22 (50.0%)	10 (20.4%)	20 (40.8%)
6	0 (0.0%)	21(60.0%)	7 (15.9%)	25 (56.8%)	13 (26.5%)	26 (53.1%)
7	0 (0.0%)	14 (40.0%)	2 (4.5%)	19 (43.2%)	14 (28.6%)	26 (53.1%)
8	1 (3.0%)	6 (17.1%)	8 (18.2%)	15 (34.1%)	11 (22.4%)	24 (49.0%)

These findings are similar to Lee and Liun (2010) and Herrmann-Abell and DeBoer (2011). Lee and Liun (2010) who examined student learning progression of the concept of energy from 6 to 8 grades and found a significantly higher amount of knowledge integration among grade 8 students than that of grade 6 and 7 students, suggesting an increase in understanding as students move up educational levels. Herrmann-Abell and DeBoer (2011) used "distractor-driven multiple-choice assessment items and Rasch modeling" as diagnostic tools to investigate students' progress in understanding as students moved from middle school to college level. Herrmann-Abell and DeBoer' findings revealed an overall increase in understanding with increasing grade level. Despite the increase in percentage of students who correctly answered in each grade in the present study, the overall number of these students is still low as can be seen in Table 3. This suggests that a large portion of students across grades were yet to master the ability to test hypothesis if given scientific ideas to be tested.

Questions 1 and 2 required the students to choose, from given answers, the correct strategy to test the given hypothesis and an explanation of why it was important that a farmer who wanted to test the effect of soil types on the growth of his carrot plants use the same amount of water for the plants planted on three different types of soil. In item 2, students were required to choose the design to test if the kind of paper used will affect how far an airplane will continue to fly. Table 2 shows that 50% and 39.1% of the students across grade levels showed misunderstanding for items 1 and 2 respectively suggesting that students did not recognize the effect of water as a contributing factor in determining the effect of types of soil and the effect of using the same design to test for the effect of kind of paper.

The third and fourth questions required students to select the appropriate experimental design for an experiment. The questions presented situations where three variables were involved in an experiment and the experimenter wanted to isolate the effect of one of them. Students were required to select from the given options "what to do" to find the possible influence of that variable and then choose the appropriate justification from the given reasons. Across grade levels only 28.5%, 54.6%, and 69.4% of students from grade 8, 10, and 12 respectively were able to provide valid and justifiable responses to the two questions regarding selecting the appropriate experimental design. This indicates that there is much needed to improve their understanding of how to design an appropriate experimental setup.

The fifth and sixth questions required students to consider handling more than two variables that may have impacted the outcomes of an experiment. For example, in question 6, participants were presented with a situation describing an experimental setup related to two boats with the boat shape and the weight as contributing factors to the boat floating. The experimental setup suggested that the shape of the boat was varied and the weight kept the same. Only 15.6% across the three grade levels (Table 2) were correctly able to extrapolate out that the shape would affect the floating of the boats and correctly considered the appropriate reason in their answers.

Table 3 showed that none of grade 8 students were able to correctly provide a correct answer with its accompanying justification for questions 6 and 7, indicating that grade 8 had difficulties understanding that when given an experiment involving two variables one of them should be allowed to change while the other be kept constant.

Questions 7 and 8 aimed to assess student ability to provide valid explanations for experimental designs. The focus was on the idea that given experimental outcomes, whether participants would be able to provide valid arguments and explanations to these outcomes. The questions described scenarios in which two variables were varied at the same time. A high level scientific understanding would demonstrate knowledge that no valid conclusions as to the impact of these variables could be drawn from such a situation. Only 12.5% and 19.5% of the participants (Table 2) correctly stated that no conclusion could be reached in such experiments as described by question 7 and 8 respectively.

3.2 Understanding of Control of Variables by Gender

The influence of gender on the understanding of the sub-ideas related to control of variables remains obvious in favor of male students when considering the two tier aspects in three of the four sub-ideas tested. More male students were able to select correct answers and provide justifications for their answers than female students. With regard to "testing hypothesis when given an idea", 48.3 of male students were able to select correct answers and provide valid justifications for their answers compared to 36.4% of female students. The sub-idea of ability to "selecting appropriate experimental setup" that requires handling more than two variables, also proved to be more difficult for female participants than males. All together 48.4% of male students compared to 42.5% of female students correctly chose the correct response and its related reasoning tier, meaning that they were able to recognize that it is important to keep one variable constant all the time if one wants to isolate the influence of the other variable on the outcome of the experiment.

Ability to "provide valid explanations to experimental setups" was the third sub-idea where male students outperformed female students (40.3% compared with 24.3%) suggesting that male students were able to argue that no valid conclusion can be obtained when varying two variables at the same time (questions 7 & 8). On the other hand, more female students were able to provide correct answers and reasons than male students in relation to the sub-idea "selecting appropriate experimental setups" where 34.9% of female students compared to 27.4% of male students who were able to provide correct answers and correct reasons to justify their answers (questions 5 & 6).

The percentages of male and female students who correctly provide answers and reasoning are presented in Table 4. The data ranges from between 27.4% and 48.4% of male students and 24.3% and 42.5% of female students. These results indicate that a large proportion of both male and females lack understanding related to ability to test hypotheses.

Table 4. Frequencies and percentage of student responses to the test items by gender

Question	Male		Female	
	Two-tier correct	First-tier correct	Two-tier Correct	First-tier correct
1	19 (30.6%)	25 (40.3%)	14 (21.2%)	39 (59.1%)
2	11 (17.7%)	39 (62.9%)	10 (15.2%)	39 (59.1%)
3	12 (19.4%)	23 (37.1%)	24 (36.4%)	27 (40.9%)
4	18 (29.0%)	42 (67.7%)	4 (6.1%)	20 (30.3%)
5	8 (12.9%)	28 (45.2%)	12 (18.2%)	44 (66.7%)
6	9 (14.5%)	15 (42.2%)	11 (16.7%)	23 (34.8%)
7	10 (16.1%)	20 (32.3%)	6 (9.1%)	39 (59.1%)
8	15 (24.2%)	15 (24.2%)	10 (15.2%)	30 (45.5%)

Examining responses given across grade levels and gender, 6 common misconceptions emerged that characterized the kind of misunderstanding held by participants (Table 5). The trends in misconceptions are similar to those identified by AAAS (2012).

Table 5. Common misconceptions displayed by participants

#	Common misconception	All Grades	Gender	
			Male	Female
1	In experiment one should examine any possible effects of all variables irrespective of which ones are kept constant and which ones are manipulated	33(21.4%)	19(20.0%)	14(23.7%)
2	It is possible to isolate the effect of the constant variable through manipulation of other variables involved in the experimental setup	39(25.3%)	27(28.4%)	12(20.3%)
3	It is possible to isolate the effects of variables that kept constant not the variables that are changed	21(13.6%)	13(13.7%)	8(13.6%)
4	It is possible to isolate the effect of all variables involved in the experimental setup irrespective whether they are changed or kept constant	29(18.8%)	19(20.0%)	10(16.9%)
5	It is possible to change two variables at the same time and isolate the effect of one of them	56(36.3%)	35(36.8%)	21(35.5%)
6	It is possible to change two variables at the same time and isolate the effect of each of these variables	52(33.8%)	22(23.2%)	30(50.8%)

The common identified misconceptions were all related to students' inability to test for specific hypotheses (misconception # 1) and inability to correctly handle the appropriate variables of interest (misconceptions 2, 3, and 4) in a context of investigation, to inability to handle more than two variables and provide valid and appropriate explanations to experimental settings (misconceptions 5 and 6).

It appears that the ability to handle more than two variables and provide valid explanatory arguments for experimental settings is the most challenging for these students as more than a third of the participants believed that if two variables in the experimental setup were changed at the same time, it would be possible to isolate the effect of one of them on the experimental outcomes. These students also believed that it would be possible to provide valid explanations for the outcomes if two variables changed at the same time. Equivalent percentages of males and females showed similar understanding for inability to handle more than two variables. Unexpectedly Table 3 showed that more females (50.8%) than males were unable to provide valid and appropriate explanations to experimental settings.

4. Discussion

The recent national and international initiatives that have emphasized the role of reasoning, critical thinking, and problem solving as necessary and highly regarded learning outcomes demand a more critical look at the outcomes of the current teaching learning processes. This means that current teaching learning processes should not only focus on conceptual understanding of science, but it must also move quickly to directions similar to those identified in science education research as 'doing science' and 'knowing about science' (Hodson, 1991). In order to achieve this goal, teaching and learning processes must focus on equipping students with the intellectual and the manipulative skills that are needed to construct and reconstruct scientific knowledge. Opportunities to present scientific investigation as and through inquiry as suggested by Arnold, Kremer, and Mayer (2014) may contribute to development of such skills as the ability to control variables (Duschl, 2008; Kuhn & Pease, 2008). Control of variables and its associated concepts are much valued procedural skills which can be categorized as intellectual and manipulative skills that drive the construction and reconstruction of the scientific knowledge. Although the findings gleaned from this study showed that the learning experiences across grade levels contributed positively to the progression of the learning of the control of variables, there is much needed to improve students' ability to handle and control experimental variables. Students across grade levels exhibited alternative conceptions of key ideas related to the skill of control of variables such as testing hypotheses, selecting the appropriate experimental setup, handling more than two variables, and providing valid explanations to the expected outcomes of an experimental setup. As a basic domain-general strategy, understanding of the control of variable allows students to develop scientific knowledge using their experimental findings. Klahr (2000) argued that control of variables is an important process skill that is essential for scientific investigations and thereby development of interpretable findings. Uncontrolled experimental setups as argued by Zimmerman

(2007) are bound to yield findings that lead to wrong inferences and conclusions.

Students' misconceptions can be interpreted in two ways. Firstly, despite the emphasis in ADEC's school curriculum on inquiry oriented learning, independent investigative learning experiences are not common in the context of this study. The most common form of inquiry used is guided inquiry where more emphasis is placed on verification purposes and the illustrative nature of activities which in effect leads to dominating the learning context and limiting the opportunities for real scientific practices that allow the learners to live and act in science-like context. The most salient contributing factors for the prevalence of such misunderstanding may be due to the lack of explicit instruction on how to carry out control experiments and apply science processes. Explicit and direct instruction on control of variables was found to be among the effective methods to improve students' ability to design reliable and control experiments (Chen & Klahr, 1999; Kuhn & Dean, 2005).

The findings of this study highlight the fact that better preparation of students for the future may require new curricula and teaching approaches that respond to and focus on not only learning scientific content but also on acquiring advanced transferable abilities such as ability to design and conduct valid and controlled experiments that yield valid and reliable findings. The findings also highlight the need to pay attention to the development of argumentation and analytical skills needed to argue for the validity of the experimental setups and choices to be made when thinking about which variables need to be manipulated and which ones need to be kept constant. Students need to focus on simple steps of recognizing variables of experiments and categorize them into categories so that decisions about their manipulations can be made. Such a skill is warranted and consistent with science education reforms that call for the introduction of scientific inquiry and logical reasoning skills that are the prerequisites for ability to solve societal problems (National Research Council, 1996). The focus on direct, explicit and focused teaching of the skill of the control of variables with explicit emphasis on multiple levels of understanding will allow students to develop better scientific outcomes and their scientific background becomes relevant to the changing scientific world.

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Appendix A

Sample items from Control of Variables Test

Please circle the answer and the reason that reflects your understanding

1. A farmer thinks that type of soil and amount of water affect the growth of his carrot plants, and he wants to find out if he is right. The farmer decides first to test if the type of soil affects the growth of the carrot plants. What would be the ideal way to carry out this experiment?

A. The farmer must use three different types of soil, place 10 carrot plants in each type of soil, and use the same amount of water for all the plants.

B. The farmer must use three same types of soil, place 10 carrot plants in each type of soil, and use the same amount of water for all the plants.

C. The farmer must use three different types of soil, place 10 carrot plants in each type of soil, and use different amount of water for all the plants.

D. The farmer must use three same types of soil, places 10 carrot plants in each type of soil, and use different amount of water for all the plants.

The reason for this answer is:

A. By using different types of soil and different amount of water, the farmer can learn about both the effect of the amount of water and the effect of the type of soil.

B. By using the same amount of water, the farmer can learn about the effect of the amount of water.

C. If he does not use the same amount of water, the farmer cannot learn about the effect of the type of soil.

D. It is NOT important to use the same amount of water because the farmer is not testing the effect of the amount of water.

2. A student thinks that there are three variables (X, Y and Z) that may affect the result of her experiment.

What should the student do to find the effect of variable X on the result of the experiment?

A. Change variable X and keep variables Y and Z the same.

B. Change variables Y and Z at the same time and keep variable X the same.

C. Change variable X and Y at the same time and keep variable Z the same.

D. Change variables X, Y, and Z at the same time.

The reason for this answer is:

A. It is important to change variable X so that its effect can be identified.

B. By changing variables X and Y the student can find out about variable X.

C. By changing variables X and Z the student can find out about variable X.

D. For the effect of variable X the student need to change the three variables.