

Conceptual understanding of force concepts in the Ugandan context: A thread assessing performance and misconceptions

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ABSTRACT

The force concept inventory (FCI) is a set of multiple-choice items that has been administered and analyzed in a number of regions across the world. The purpose of this study is to evaluate students' comprehension of force concepts, using a thread that examines and analyzes the most common force concept misunderstandings among students. The FCI is distributed to 1,440 senior four students from various Ugandan schools. The ITEMAN software is used to assess students' performance. Then a few FCI items are examined to acquire a better grasp of the students' misunderstandings. Using the Gnuplot software, we displayed the students' total scores versus their percentage scores for each FCI alternative choice, which provides greater visual confirmation of the findings than statistical analysis. The findings show that misunderstandings dispersed in accordance with students' performance. The distractors are the most appealing of the analyzed FCI items, with the highest percentages of students picking each alternate option. Imitating that students enter physics classes preconceived about their prior knowledge, viewpoints, ideas, and values. As a result, this study underlines to Ugandan physics teachers that students have misconceptions. Physics teachers and students should interact in an active learning environment using conceptual change methods to correct misconceptions.

Keywords: conceptual understanding, force concepts, force concept inventory, performance, misconceptions

INTRODUCTION

Previous concepts gathered prior to new learning by students have a significant impact on the building of new knowledge in science. Physics is a key science discipline taught in secondary schools that discusses physical occurrences and how they relate to man's daily existence. There is a chance that cultural ideas impact how concepts are learnt and manipulated. For meaningful learning to occur, physics teachers must support their students in applying their knowledge in ways that rely on their cultural experiences. Learning is understood to be culturally dependent in that students' capacity to reason on applied scientific problems usually linked to their beliefs (Chala et al., 2020). Most natural phenomena and challenges in African life are usually difficult to explain using scientific understanding. This is due to the fact that mythology and superstitions abound in the majority of students' beliefs. It is based on the power of witchcraft and evil spirits, which are prevalent in African life but are not explained scientifically. Students' everyday experiences in the classroom, in the environment, and in the scientific world lead to a divergence. With the majority of students finding it difficult to scientifically describe, analyze, evaluate, and forecast natural phenomena (Driver et al., 2014).

Understanding of the subject matter is essential for good physics instruction. Physics teachers must have pedagogical expertise in the field, understanding of students' learning issues, and sympathy for students' shortcomings in order to teach physics. In recent years, the Uganda National Examination Board (UNEB) and higher education institutions have expressed concern about poor academic performance in physics. The performance of candidates produced by Ugandan secondary schools, where passes in physics are below 20% at distinction and credit level, has been disputed by UNEB (2019). Various scholars attribute low performance to a variety of factors, including a substandard learning environment, unskilled instructors, students' attitudes, career desire, and parental and peer influence. However, the majority of academics believe that students' cognitive styles toward physics have a significant impact in their poor performance. Furthermore, physics teachers' ineffective pedagogical techniques encourage students to focus on preparing answers rather than understanding concepts (Komakech & Osuu, 2017; UNEB, 2014). The Ugandan government has been working with a number of science projects, including Secondary Science Teacher Education in Sub-Saharan Africa (TESSA), Secondary Science and Mathematics Teachers (SESEMAT), and others to improve the efficiency of science and mathematics teaching and learning, with a particular focus on secondary science and mathematics.

Students' comprehension is investigated, science is made realistic, science is made meaningful and actual, problem-solving and inventions are encouraged, and challenging concepts are addressed. Despite government initiatives, students continue to receive poor results in science disciplines, particularly physics, and only a tiny percentage of science students' progress to the upper secondary level (Ssemपाला, 2017). The persistently low and unsatisfactory performance rate is a clear sign that the secondary education system is troubled, diseased, and decaying, and that it demands immediate and comprehensive reform and repair. The drop in student performance has become such a trend that educational authorities are dismissing it, which is concerning (UNEB, 2019).

Physics teachers have a significant impact on the efficacy and accomplishment of students in the subject. Physics instructors must not only add new concepts to students' existing knowledge, but also realign their thinking and enable them to construct new ideas that may disagree with their current beliefs. Physics educators and researchers have intensified their efforts to discover and comprehend the nature and scope of elements that influence learning and accomplishment in physics in order to align students' thinking. As a result, the study's goal is to use a thread to test students' conceptual comprehension of force concepts in the Ugandan context, as well as misconceptions about them. Around the last four decades, physics education research (PER) has been undertaken all over the world, offering information on how to increase physics student outcomes.

Using concept inventories (CIs), the PER community has developed a way to measure the effectiveness of pedagogical practice and students' learning gains during the last three decades. A CI is a research-based multiple-choice instrument used to assess learners' conceptual comprehension (Porter et al., 2014; Sands et al., 2018). Each question (item) has one correct response and four to five erroneous responses, known as distractors, based on common student misconceptions, using a variety of fundamental concepts from the physics domain. The concept of a misconception, sometimes known as an alternate conception, is critical to mental understanding measurements. CIs are not the same as final exams in that they do not pretend to cover everything in a subject. CIs are designed to include students' everyday concepts and natural language in a multiple-choice format. In order to perform well on these types of assessments, students must have a thorough comprehension of the concept(s). Over the last 30 years, CIs have had a significant impact on physics education reform. Their impact on physics education is meant to encourage educational improvements (Hake, 2011). The broader PER community uses evaluation instruments established for student thinking studies to provide uniform teaching and learning measurement. They help physics educators figure out what their students know and can do in class.

In this study, the force concept inventory (FCI) is used. It is the first and most well-known CI (Hestenes et al., 1992). The FCI is created to investigate commonsense ideas about motion and force that contradict Newtonian conceptions. We decided to use the FCI in this study because of its success in the field of physics and subsequent educational reforms. The FCI, as a diagnostic instrument, comprises six conceptual domains that are consistent with the National Curriculum Development Centre's (NCDC, 2008) physics syllabus for Uganda's Certificate of Education. The NCDC content syllabus described in the preceding part of methodology is appropriately covered by the FCI conceptual areas. The general NCDC physics education objectives are covered, which include establishing effective means of assessing the prevalent misunderstandings among secondary school physics students. The FCI's main goal is to identify a distinction between Newtonian notions and commonsense alternatives proposed by individual students. The FCI test is a reliable assessment tool for measuring the quality of education since it identifies the learner's misconceptions about force and motion (Hake, 1998).

As a result of this research, the science education community will be better equipped to advocate for the use of alternative testing methods that have yet to be explored, such as CIs, observations, peer teaching, and multi-teacher rating. In comparison to traditional pen-and-paper assessments, these would measure a learner's intelligence level, which is otherwise hard to measure with a single mode of measurement. In light of the foregoing, our research is a step toward a larger project we are working on, which entails creating a Ugandan context-specific inventory (circular motion concept inventory). To track learners' shifts in conception, analyze teachers' instructional activities, and identify learners' circular motion alternative conceptions (Kirya et al., 2021). The authors argue that adopting a credible and globally recognized FCI to examine students' previous experiences at the secondary school level is essential. This empirical study reveals gaps in the field that will be highly useful to young generation researchers, education sectors and associated, Ministry of Education and Sports, government, and non-governmental organizations. The results of the FCI conceptual study in various regions are summarized in the next section.

LITERATURE SURVEY

The Concept of Constructivism

Constructivism is a dominated thought since the 18th century. Its beginnings are in theory, but it has since been used to sociology, anthropology, social psychology, and education. The term constructivism has been defined extensively. Depending on the author's meaning and interpretation, the definition can be different. Constructivism is defined in this review as a mechanism (Behera, 2012) through which students develop their perception, truth, and knowledge of the environment in which they live by modeling their perceptions and relationships within the educational setting. Knowledge is defined as dynamic, genetically influenced, socially and culturally influenced, and hence pre-objective in philosophy. Constructivism is a philosophy that is based on scientific notions and knowledge into how students learn. When learners come across something new, they must compare it to their previous actions, beliefs, and perceptions, which may cause them to change their minds or dismiss the new information as useless. No matter how it is expressed, understanding is in the minds of learners, and the subject matter of learning has no choice but to develop what the learner learns based on their own experiences.

Despite, the fact that constructivism is not a new concept it has gained attention in recent years. The principle of constructivism can also be found in the philosophies and literary works of intellectuals such as Socrates, Plato, and Aristotle who wrote about knowledge facts before John Dewey. The educational literature acknowledges eighteen various forms of constructivism in terms of procedural, radical, didactic, critical, feminist, postmodern, and dialectical aspects. Several philosophers and academics have divided constructivism into three categories; sociological, psychological, and radical constructivism (Chellammal, 2016; McLeod, 2019). This review is not interested in the numerous divisions that explain the extensive distinctions according to Jean Piaget's study as cognitive constructivism, Lev Vygotsky's research as social constructivism, or von Glasersfeld's supported radical constructivism. In the following parts, we look at the constructivism paradigm and how it relates to scientific education and constructivism.

Education and Constructivism

Constructivism in education is essentially based on Piaget's cognitive growth theory, which was published in 1970 as a tangible component of his biological adaptation. After sensory-motor intelligence, Piaget in 1999 identified and classified four fundamental stages of a person's cognitive development. Both social behavioral neuroscience and epistemology inform constructivism in scientific teaching. Constructivism has been accepted by a rising number of scientific education scholars since the 1980s (Chellammal, 2016; Juvova et al., 2015). Constructivists agree that science education should be centered on the students, and that teachers should act as facilitators via imparting instruction rather than as agents who pass on knowledge. The social context increases learner focus through subject matter teaching, emphasizing the recognition of existing values, facts, and experiences that learners bring from other places as part of the philosophy. Previous learning experiences have been shown to have a major impact on how students make meaning of what they have learned.

Constructivist Science Teaching

Knowledge cannot be transmitted directly from a teacher to a learner, according to the Education constructivism theory. The learner must be willing to actively voice his or her various points of view (pseudoscientific ideas). The teaching philosophy is important because it explains how to erase or redirect current thinking in order to induce a cognitive shift in students. Science educators offer the constructivist learning strategy during educational exercises (Bächtold, 2013). Constructivism is being identified by teacher educators as a modern philosophy capable of overcoming any science teaching-learning issues and is a good concept for both teaching and undergraduate education.

Learners often have past conceptions that are "alternatives" to scientific concepts that exist despite teaching or coexist with present knowledge (Bächtold, 2013). They remain active in a variety of "contexts" and have become "natural" as a result of prior students' experiences. Teachers of science who use constructivism in their pedagogical efforts must cope with learners' preconceptions. The goal should be to "alter" existing beliefs and remove the "difficulty" or "obstructions" that come with learning scientific notions.

Constructivists say that rather than functioning as authorities who pass information on to students, physics educators should be learner-centered and promote study. This aids educators in assessing students' comprehension. Develop teaching tactics that increase cognitive stress and allow students to better shift their alternate interpretations. Because learning relies on the shared experiences of learners, peers, and teachers, learners must engage effectively in learning. So it comprises a small number of concepts and places a greater focus on understanding, philosophical shifts are regarded as gradual (Singh & Yaduvanshi, 2015).

The Pedagogical Constructivism and Use in Science Education

The endeavor to involve the student actively in the learning process is emphasized throughout the educational system's theory. Constructivism in education recognizes the importance of learners in the development of personal understanding. Hendry in 1996 developed key constructivist concepts for teaching/learning methods in the classroom (Matthews, 2012). The following are some of the principles:

1. Even in the mind of the student, there is intellectual capacity. At the same time, information is available in the minds of both the learner and the schoolteacher. There is no such thing as a chalkboard, books, web sites, speaking educator or student, or activities arranged by instructors and learners.
2. Learners form their perspectives of events based on their previous experiences. Students and instructors attach meaning to instructional information (e.g., records, photographs, artifacts, audio-visual resources, and digital tutorials) based on their current experience and beliefs.
3. Knowledge is based on inward contact with the universe. Teachers or teaching practices in particular, do not change students' ideas; rather, students' ideas are constructed from the inside out as a result of their interactions with the environment of which educators are a part.
4. There is no such thing as certain knowledge. Because knowledge is vulnerable to misinterpretation of conclusions or axioms on which evidence is founded, it can never be guaranteed. Teachers are seldom sure of the words they employ to communicate anticipated knowledge to students, and vice versa.
5. Scientific knowledge is created by a single brain and body that exists in the same universe. Learners from many countries and communities share the same ideational knowledge of natural phenomena, according to a study of their everyday conceptions.
6. Perception and action are the foundations of knowledge. Through perceptual and cognitive-action, students receive new information by comprehending and acting on classroom activities, as well as talking with the teacher and/or each other.

7. Building knowledge takes time and effort. Teachers must endeavor to encourage students' positive actions in order to create an environment free of danger and fear from the outside world. They should seek for a "friendly learning environment."

In science education, success is frequently defined as the learner's ability to develop, establish, and adapt meaning in a way that depends on existing knowledge. Learners must be motivated to apply what they have learned so far to a new situation in order to achieve a better understanding (Matthews, 2012). The section that follows examines research that used the FCI to assess conceptual gain and existing misunderstandings.

A Review of Students' Misconceptions

Students' conceptions grow and alter as a result of their daily experiences, and they become crucial components of their lives. Students develop notions in their thoughts as a result of their classroom experiences or daily activities outside of school (Kaniawati et al., 2019). Because students have varied life goals, their experiences will vary depending on whether they have the correct or incorrect scientific concepts. New physics teachers typically imagine student as "blank slates" with which to inscribe a wide range of physics notions. Students are not "blank slates," or else teaching and learning would be a breeze. Before arriving to formal schooling, students get an awareness of daily activities. Students' perceptions of formal notions presented, as well as how they categorize and interpret them, are influenced by their knowledge, skills, experiences, and beliefs received from the natural world (Bozzi et al., 2019). Students communicate their ideas without relying on scientifically validated scientific notions connected to the area of study.

Students' capacities to reason and learn new knowledge are influenced by their existing knowledge and experience. Misconceptions (also known as "alternative conceptions", "misunderstandings", or "preconceptions") are the differences between students' and scientists' conceptions. Because new knowledge is constructed on the foundation of previous knowledge, physics teachers must struggle with the preconceptions that students bring with them. As a result, changing students' preconceptions from inaccurate to correct information is difficult and time-consuming because the misconceptions are deeply established in their prior knowledge paradigm (Kaniawati et al., 2019).

A number of academics in the PER discipline are investigating student misunderstandings to comprehend learners' ideas that are not scientifically valid. Students' understanding of notions that are incorrect according to expert theory, if allowed uncontrolled, always impair students' achievement. A variety of strategies are used to assess student misunderstandings. Instruments can include concept inventories, multiple-choice questions, concept maps, description questions, and graded questions (Gurel et al., 2015). The instruments include diagnostic test questions that are used to assess students' misconceptions and include indications of scientific literacy. The focus of this study is on the force concept inventory (Hestenes et al., 1992) as the tool for determining students' misunderstandings.

Hestenes et al. (1992) investigated and studied college students' "common sense" ideas about how the physical world works based on personal experience. In most ways, common sense assumptions about motion and force are inconsistent with Newtonian concepts. Students are enticed to cope with the subject matter through rote memorizing because traditional physics training produces little change in their beliefs. A survey uses multiple-choice diagnostic pretests and posttests, as well as interviews, to create the misconceptions (Hestenes et al., 1992). An object slows down when there is no net force; an object moves at a steady pace when there is a constant force; and an object requires an impetus to maintain motion. As a result of the survey, taxonomy of "common sense" conceptions that contradict Newtonian theory is developed as a guide to instruction. According to Hestenes et al. (1992), there should be a conceptual criterion of 60% for a student to be regarded grasping the Newtonian concepts on the inventory. Below the criterion, there is a knowledge gap that requires appropriate remediation, with misunderstandings taken into account.

Fadaei and Mora (2015) looked at high school students' misconceptions about force and motion before and after formal (conventional) training, as well as their stability. Students of various educational levels and ages frequently hold commonsense alternatives. Students' misunderstandings in mechanics, from elementary through high school, and university students' grasp of Newton's laws, suggest that certain inaccurate assumptions about the physical world exist. Because Newton's laws of motion play such an important part in exploring the universe, Fadaei and Mora (2015) looked at how students used the FCI to help them build a deeper understanding. The method used to quantify changes in performance is a defining aspect of the pre- or post-testing design, according to the commonsense beliefs. The students' average percentage results imply that the traditional approach is effective in promoting learning in various areas of the topic. However, it is discovered to be unsuccessful in some cases of FCI items in other regions of the world. The number of erroneous replies significantly increased, indicating that traditional teaching methods are ineffective in encouraging learning and correcting misconceptions. Traditional instruction has no bearing on common sense misconceptions (Fadaei & Mora, 2015). A physics curriculum should be revised and new contexts planned to assist students think like scientists and explore real-life occurrences in mechanical scenarios.

As students precede through their science education levels, the existences of alternate concepts among learners are reinforced and extremely difficult to modify (Nik-Daud et al., 2015). Nik-Daud et al. (2015) looked at some of the literatures on introductory physics misconceptions and problems among high school and university students. The generalized basic notions of students' misconceptions about forces and motion in mechanics have been identified in previous studies in scientific education (Driver et al., 2014). Namely, (i) there is a force acting if there is motion; (ii) there is no force acting if there is no motion; (iii) there cannot be a force without motion; when an object is moving, there is a force in the direction of its motion; (iv) a moving object stops when its force is used up; (v) a moving object has a force within it that keeps it going; and (vi) motion is proportional to the force acting. New instructional strategies focusing on conceptual change should be implemented in physics education to eliminate students' alternative ideas. Teachers should stress the quality of students' understandings rather than just surface learning of exam scores

to encourage deep understanding of subjects among students (Nik-Daud et al., 2015). As a result, conceptual comprehension is critical, and it should be a primary focus of instructors' interest in physics teaching and learning.

To summarize, a number of PER research are using the FCI to explore the level of students' conceptual understanding, as well as the effect of educational level on conceptual understanding of Newtonian mechanics. The FCI has been used to investigate students' misconceptions about Newton's laws through a number of applications. It is the first time in Uganda that FCI has been administered to secondary school students in order to assess their performance and uncover misconceptions. In the Ugandan setting, there is no data available for FCI-based research. As a result, in order to assess the FCI's suitability, concept items must be analyzed utilizing the constructivism approach in Ugandan secondary schools and compared to earlier empirical research studies completed by PER academicians.

METHODOLOGY

The Force Concepts in the UCE Physics Teaching Syllabus

The Ministry of Education and Sports provides a physics teaching syllabus for UCE following the National Curriculum Development Centre's (NCDC, 2008) recommendations. NCDC developed a four teaching program that organizes the content in the present physics syllabus into a pedagogical hierarchy. Creating a society that knows and values physics, as well as comprehending naturally occurring occurrences and students' interpretations, are among the broad physics education goals. Newtonian Mechanics is a general main topic in the UCE teaching program. The scope is clarified by subtopics such as introduction to forces, turning effect of forces, and centre of gravity, machines, work, energy, and power, pressure, motion, vector and scalar quantities, linear momentum, Newton's laws of motion, friction between solids, mechanical energy, Archimedes principle, and fluid movement, and properties of materials under stress and structures. The subtopics properly cover the content covered by Hestenes et al. (1992).

Force Concept Inventory

The FCI is used as a research instrument in this study as a diagnostic tool. FCI is a set of 30 multiple-choice questions (Hestenes et al., 1992) frequently used in beginning physics courses to test and analyze student conceptual comprehension of Newtonian mechanics. Each item depicts a physical situation and offers five options. One of the five choices corresponds to the proper physical notion, whereas the other four correspond to popular alternative views. Kinematics, Newton's equations of motion, the idea of superposition, and many types of force are all covered in the FCI. The FCI is no longer just another physics test. It assesses a student's overall grasp of Newton's concept of force in relation to motion. Furthermore, the FCI's selection is justified because it identifies and categorizes the learners' misconceptions.

Validity of the FCI Instrument

Content-related and face-related evidence are used to determine the validity of the FCI. FCI was examined by four physics educators for content-related validity. A copy of the FCI test and a brief description of the data collection procedures were given to each expert. In addition, the four experts were asked to remark on the clarity of each item's phrasing as well as its complexity. The four experts were asked to make suggestions on how the test items and their wording may be improved. The phrasing of the items and their complexity were discussed by both experts and no issues were raised. The items were appropriate in terms of the objectives and their applicability to Ugandan secondary school physics. The FCI test did not undergo any changes in terms of the language of the test items based on the comments provided by the experts. Following the experts' evaluation, we conducted a field test to determine face validity. A set of five secondary school students (not included in the study population) were asked to provide feedback on the instrument's clarity, language, thoroughness, ease of use, and appropriateness. The test's appropriateness was strengthened as a result of this approach. This indicates that the FCI test did not address any potential sources of student readability difficulties. As a result, the FCI test is administered to a large number of secondary school students.

Sample of the Participants

In this study, the target group is senior four students in Ugandan secondary schools, both male and female. In senior four, the students are between the ages of 15 and 17. As a representative sample, one thousand four hundred forty senior four students are selected at random from various schools and districts. A multi-stage sampling process was employed to randomly choose students in Ugandan secondary schools. Six secondary schools were selected from Uganda's four geographical areas (East, West, North, and Central). In Ugandan secondary school data, the 1,440 is regarded representative and generalizable to analyze students' statistics (Taherdoost, 2016). Sixty students from the multi-stage sampling school were chosen at random for the FCI test by their physics teachers.

Physics teachers at the sampled schools assisted in the preparation of a testing environment for the FCI test. The students were encouraged to respond to the FCI test items based on what they thought and believed is correct. They were told not to copy their colleagues. They were discouraged from disrespecting the UNEB guidelines and regulations by their physics teachers. Teachers were urged not to conform to the instrument's time limit, allowing those who requested more time to be given. A total of 1,440 response sheets were collected from students around the country who responded from their respective testing schools. The response sheets of the students are scrutinized. Before being organized for processing and analysis, the survey response sheets are scanned and cleaned. Nine hundred and forty-one clean response sheets were coded and analyzed. In the following section, we will go through data analysis approaches.

Table 1. Summary of the students' performance

Statistics	Scored items
N	941
FCI items	30
Mean	6.52
Standard deviation	2.282
Minimum score	1
Maximum score	15
Mean P	0.217

Table 2. Validity index of the FCI items

Validity index	Classification	Items of FCI	Coefficients
<0.15	Invalid	3, 4, 7, 14, & 20	0, 0.03, 0.07, 0.04, & -0.01
≥0.15	Valid	-	-

Table 3. The difficulty level of items on the FCI test

Level of difficulty	Classification	Items of FCI	Coefficients
0.20-0.00	Difficult	3 & 20	0.13 & 0.09
0.21-0.25	Fair	4 & 7	0.22 & 0.23
0.26-0.74	Moderate	14	0.43
0.75-1.00	Easy	-	-

Analysis of Data

We were able to generate the data matrix and item control files by converting the response sheets into Microsoft Excel spreadsheets. The ITEMAN program is used to statistically analyze the two files (item and test analysis manual). This program is well-suited to multiple-choice items, such as the FCI items utilized in this study (**Appendix A**). The program's descriptive statistic variables were of interest for further investigation. These are used to evaluate FCI items selected for analysis representing each of the conceptual domains designed. We established their applicability based on test item qualities like validity, reliability, difficulty level, discrimination powers, and distractors' performance.

DISCUSSION AND INTERPRETATION OF DATA

The FCI was used as a survey instrument with 30 MCQs to collect data on students' concepts and beliefs regarding force and motion. Students in various schools across the country were given the FCI to test. The students' ideas and beliefs were limited to the FCI item circumstances in the inventory, to which they answered by selecting the option that they felt and believed was correct. The following results were acquired after collecting, tabulating, and analyzing student responses using the ITEMAN software.

According to a summary of descriptive statistics, 30 FCI items were investigated, and 941 students completed the test by responding to all FCI items (**Table 1**). The students who took the test were both boys and girls from secondary schools. The average score of the students was 6.52, with a standard deviation of 2.282. The highest-scoring students received a maximum of 15 correct answers, while the lowest-scoring students received only one correct response. The mean score (mean P or difficulty index) of the proportion of students who correctly reply to the test item as a percentage of the total number of students is 0.217. This is an indicator that the FCI test items were difficult for the students to complete. We then proceeded to analyze five FCI items (3, 4, 7, & 20) in order to gain a more complete understanding of why the students' performance is unappealing. The psychometric index study of the FCI items was the first step.

The most important component in developing any instrument is establishing the construct and matching content validity. The point-biserial correlation was used to assess the validity of FCI items. In classical item analysis, a conventional procedure is employed (Attali & Fraenkel, 2000).

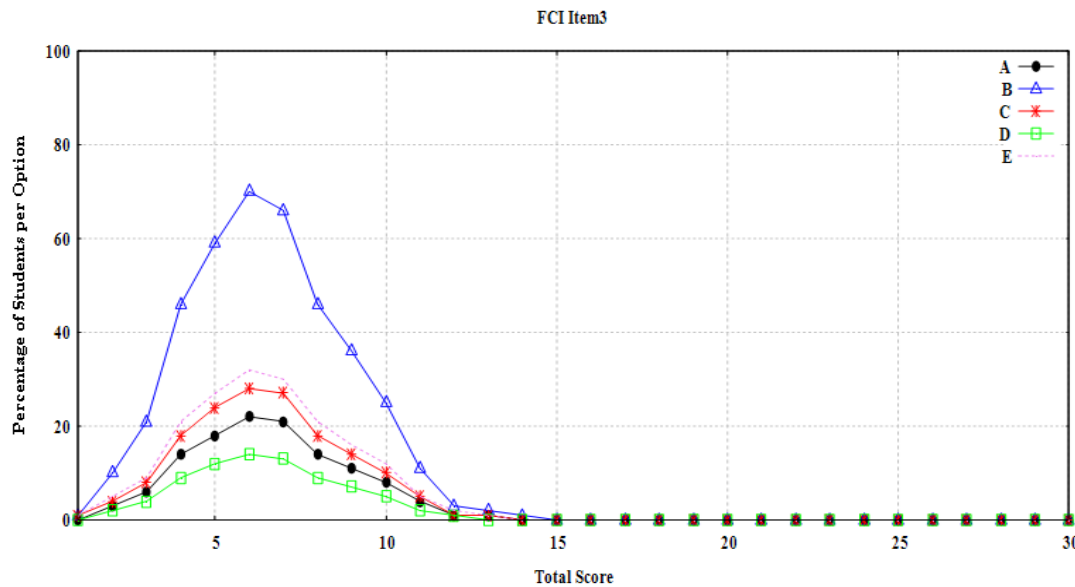
As a secondary statistical analysis to the content, **Table 2** illustrates the distribution of FCI items chosen based on their validity. For the point-biserial correlation, we set a minimal threshold value of 0.15; however, scholarly literature suggests that good idea items have a point-biserial over 0.25 (Attali & Fraenkel, 2000). The validity of the selected FCI items in this educational environment was judged using a minimal threshold value in this study. The 5-point biserial coefficients (100%) were all less than the threshold value. The findings of **Table 2** appear to be at odds with the experts' guidance in the methodology section when it comes to analyzing the content validity of the FCI instrument. This finding backs up the students' average performance in **Table 2**.

Table 3 shows the difficulty level of the items chosen. The ITEMAN-calculated distribution of FCI items by difficulty level illustrates the results of the computation and their categories. None of the items selected fell into the 0.75-1.00 easy category. The students appeared to struggle with notions of types of forces (item 3) and kinematics concepts of velocity differentiation from position (difficult). Students struggled with the third law of motion (item 4) and vector addition of velocities (item 14) ideas. Item 7, which depict Newton's first law, was rated as moderately easy. The item 20 emphasizes the importance of grasping the concepts of position, velocity and acceleration. The probability of a certain number of students selecting an alternate option is shown in **Table 1**.

Table 4. Percentage of students who responded to each of the five options on the FCI's five items

Alternative options	FCI item number				
	Item 3	Item 4	Item 7	Item 14	Item 20
A	13.1	46.3	22.2	42.5	29.6
B	42.3	21.9	32.2	33.7	25.2
C	16.9	07.9	12.4	09.6	27.4
D	08.5	12.5	10.6	10.8	08.3
E	19.2	11.4	22.5	03.4	09.5

Note. The **bold** values are the keyed alternative options

**Figure 1.** Item normal curves for FCI item 3 (key score is C)

We calculated the percentage of students that chose an alternate option for each of the five alternatives for each of the items we chose. We chose five items for graphical presentation after doing this analysis item by item for all 30 FCI items. For each of the five items, we created a normal curve graphical presentation with percentage replies for each alternative option as the dependent variable and the overall score as the independent variable. Five normal curves are displayed in each graphical presentation, one for each alternative option. The five FCI items examined fall under several categories of misconceptions. Kinematics, active forces, impetus, concatenation of influences, action-reaction pairs, and other motion influences are the categories. Hestenes et al. (1992) compiled a complete taxonomy of the misconceptions measured by student responses to Newtonian thinking. The graphical presentations graphically exhibit the FCI item data sets in an understandable way and provide all of the information on a single page with good illustration for function distractors comparison.

Graphical Presentation of the Distractors and the Key Options

This study examines all erroneous answers for each FCI item in order to identify the most common and persistent misconceptions. The percentage replies of the students to each alternate choice for the five items are shown in **Table 4**. Those are the ones depicted visually. The percentage of the number of students selecting an option is plotted against the total score.

Distractors were assigned to item 3 (**Figure 1**): B (speeds up as it falls due to gravitational attraction, then attains constant speed), E (falls due to the combined effects of gravity), and C (in the beginning, speeds up because of an almost constant force of gravity acting). Other than the keyed choice C, the three distractors caught the interest of students with higher percentages (reaches a maximum speed quite soon after release and then falls with constant speed). This indicates that students' comprehension of gravity increases as objects fall (Moradi et al., 2018; Nik-Daud, 2015).

Only one distractor A (the truck exerts more force on the vehicle than the car exerts on the truck) receives a larger percentage of responses in item 4 (**Figure 2**). The main alternative option B (the car exerts more force on the truck than the truck exerts on the car) demonstrates that students are not well-versed in the scientific concepts of impulsive forces. Furthermore, students were able to deduce that a greater mass equals a greater force. As a result, the findings confirm Pfundt and Duit's (1994) findings that students have a misperception about motion in the concatenation of influences category: motion is decided by a compromise between the forces operating on the object.

Item 7 tests students' awareness of motion direction by having them swing a steel ball on a string in a horizontal plane in a circular pattern (**Figure 3**). When the thread abruptly breaks near the ball, the direction was to be determined. The keyed option B was more appealing to the students emerging with a slightly higher number of students' frequency responses. In addition to the findings of Driver et al. (2014), students have the misunderstanding that a moving object has a force within it that keeps it moving. As a result, after the string breaks, it is impossible to determine the proper direction of motion.

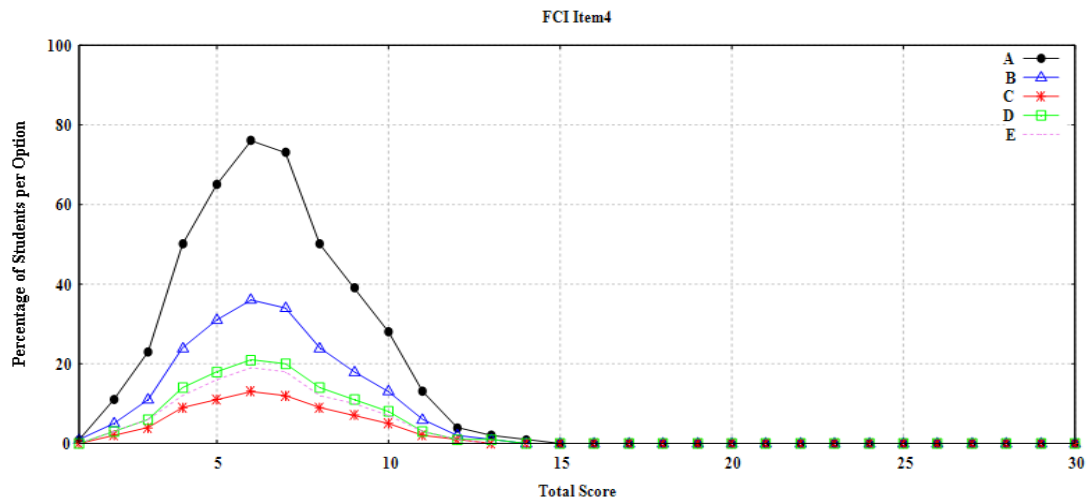


Figure 2. Item normal curves for FCI item 4 (key score is E)

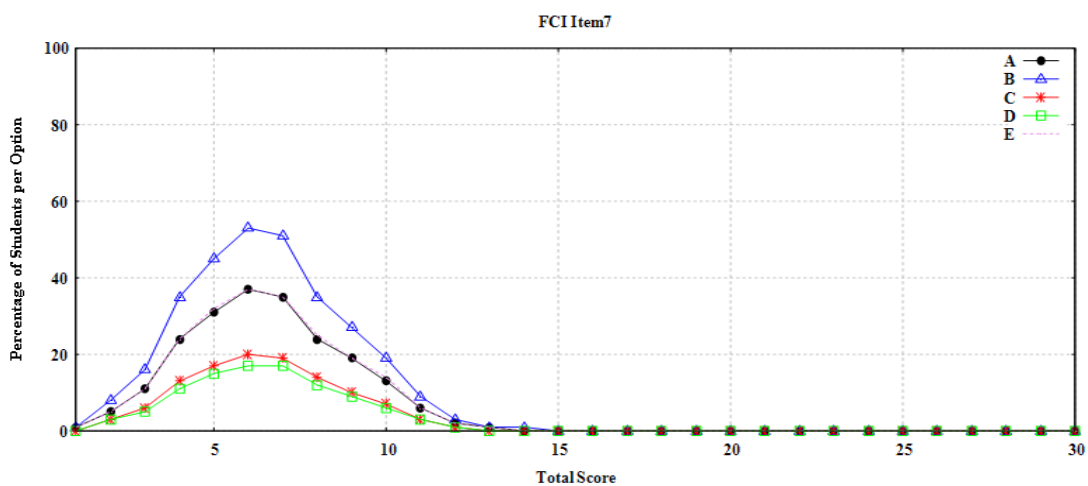


Figure 3. Item normal curves for FCI item 7 (key score is B)

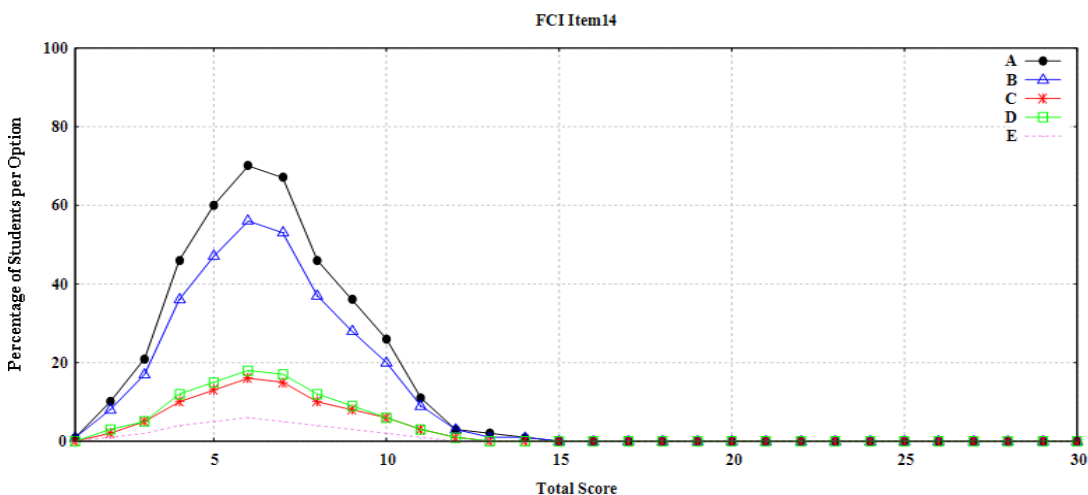


Figure 4. Item normal curves for FCI item 14 (key score is D)

Item 14 is an intriguing test item that indicates a lower number of students properly answering the question (Figure 4). Item 14 examines gravity and free fall in the context of an object falling from a horizontally flying plane. The students were supposed to figure out and identify the path a bowling ball would take if it fell out of the cargo bay of an airplane. The students were to imagine themselves as a person standing on the ground looking at the plane (see item 14). The item demonstrated that the majority of students had preconceptions because they did not correctly score the item. As a result, physics instructors are expected to recognize aspects of students' reasoning that does not extend towards a correct Newtonian dimension and then use the appropriate approach to conceptually transfer the low ability beyond the threshold mark.

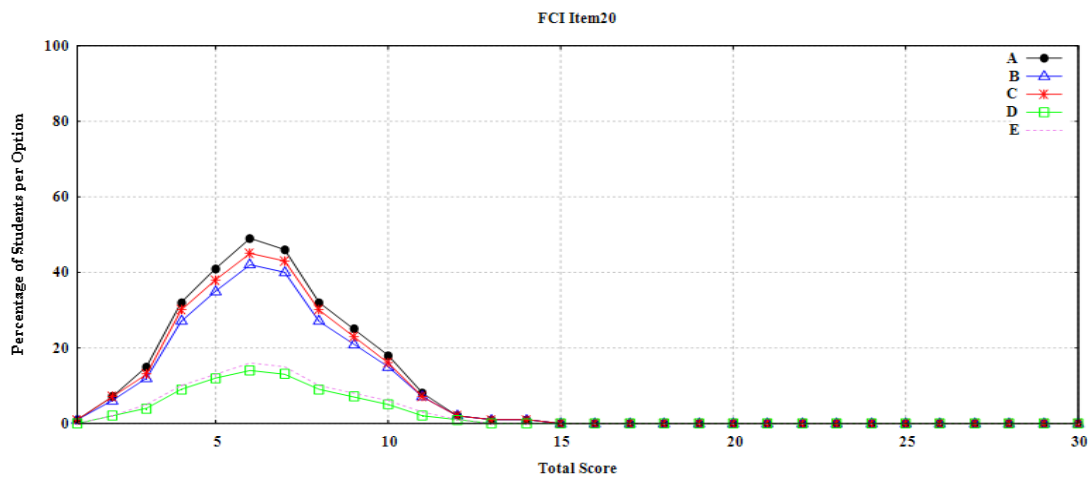


Figure 5. Item normal curves for FCI item 20 (key score is D)

Item 20 tests students' knowledge of object positions and accelerations (Figure 5). Because the distractors were more appealing than the keyed option, students' performance on this item was relatively low. Higher percentage responses were received for the distractors A (acceleration of "a" is greater than the acceleration of "b"), B (acceleration of "a" equals the acceleration of "b"), and C (acceleration of "b" is larger than the acceleration of "a"). A few students chose the keyed alternative option D (the acceleration of "a" equals the acceleration of "b". Both accelerations are zero). As a result, the biggest number of students selecting distractors indicates that they are struggling with concepts of position; distance, velocity, and acceleration are all difficult to distinguish.

CONCLUSIONS

Upon completing the secondary school physics curriculum, we decided to investigate which misconceptions were prominent in the students' minds when they answered the FCI questions. We discovered that students have difficulty understanding concepts in "force and motion" concepts. The difficulty and misunderstandings of the students' efforts were reflected in their grades. The average grade of 6.52 is well below average. The students were unable to choose the proper response from the multiple-choice options offered, indicating that they had only a partial understanding of the FCI test items. The FCI items were found to be valid in terms of construct validity and content validity, as well as relevant and linked to the goals of the Ugandan physics teaching syllabus, according to the physics educators. However, utilizing point-biserial correlations to support the experts' suggestions concerning the validity of the FCI, the students' responses disagreed. The point-biserial correlation coefficients were used to judge the validity of the FCI item in this educational context, and all of the selected FCI items were found to be invalid below the minimum threshold value of 0.15. The distractors of the four FCI items were the most appealing, with the largest percentages of students choosing each alternate option. As a result, students come to physics classrooms with preconceived notions about their prior knowledge, perspectives, beliefs, and values. As a result, students develop prejudices and beliefs based on scientifically incorrect assumptions. This study's students have misconceptions. But, if physics teachers and students collaborate in an active learning environment using conceptual change methodologies, this can be easily remedied. The study will awaken teachers and students to a variety of concepts for enhancing physics learning and comprehension, and eventually attaining meaningful learning.

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APPENDIX A

Analyzed FCI Items

The selected FCI items discussed in this paper are presented. Questions 3, 4, 7, 14, and 20 are included in the students' responses and our analysis. The questions were carefully selected to match into one of Hestenes et al.'s (1992) conceptual domains.

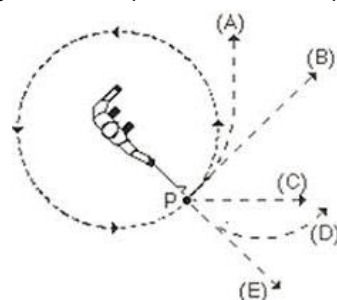
3. A stone dropped from the roof of a single story building to the surface of the earth:

- (A) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
- (B) speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the earth.
- (C) speeds up because of an almost constant force of gravity acting upon it.
- (D) falls because of the natural tendency of all objects to rest on the surface of the earth.
- (E) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

4. A large truck collides head-on with a small compact car. During the collision:

- (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
- (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
- (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
- (D) the truck exerts a force on the car but the car does not exert a force on the truck.
- (E) the truck exerts the same amount of force on the car as the car exerts on the truck.

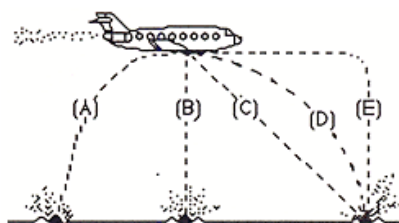
7. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure.



At the point P indicated in the figure, the string suddenly breaks near the ball. If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?

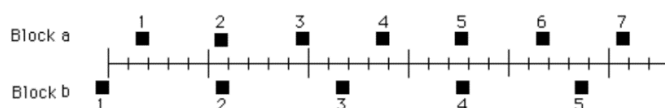
- (A) A
- (B) B
- (C) C
- (D) D
- (E) E

14. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As observed by a person standing on the ground and viewing the plane as in the figure at right, which path would the bowling ball most closely follow after leaving the airplane?



- (A) A
- (B) B
- (C) C
- (D) D
- (E) E

20. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.



The accelerations of the blocks are related, as follows:

- (A) The acceleration of "a" is greater than the acceleration of "b".
- (B) The acceleration of "a" equals the acceleration of "b". Both accelerations are greater than zero.
- (C) The acceleration of "b" is greater than the acceleration of "a".
- (D) The acceleration of "a" equals the acceleration of "b". Both accelerations are zero.
- (E) Not enough information is given to answer the question.