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Review of Research in Student Conception Studies and Concept Inventories: Exploring PER Threads Relevant to Ugandan Context

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Abstract

This paper is motivated by some of the problems and challenges in physics education faced in the Ugandan context. It has been reported by the Uganda National Examinations Board (UNEB) that the percentage of students passing in physics is below twenty per cent at distinction and credit level. Students turn to problematic and counterproductive learning approaches such as rote learning and memorisation of problem-solving steps. That refers to a shortage of high-quality teacher education programs and a reliance on traditional pedagogies such as lecture approaches. The paper focuses on student conception studies, associated frameworks and their compatibility with constructivism. The debate then shifts to physics concept inventories, their impact on physics teaching, and their relevance in Ugandan education. In Ugandan schools, educational assessment is now done mostly through conventional examinations. The use of alternative forms of assessment that have not yet been used, such as CIs, observations, active learning, and multi-teacher rating, was advocated due to a deficiency in the practice of continuous assessment in the Ugandan education system. The focus of this paper is on concept inventories as an assessment and diagnostic tool that takes into account insights from students' conception studies.

Keywords: student conceptions; concept inventories; misconception framework; Ugandan assessment system

Introduction

Physics is considered a difficult subject to teach and learn across the world. The teaching of physics in sub-Saharan Africa is still dominated by teacher-centred instructional methods (Uwizeyimana et al., 2018). This paper is motivated by some of the problems and challenges in physics education faced in the Ugandan context. It has been reported by the Uganda National Examinations Board (UNEB, 2019) that the percentage of students passing in physics is below twenty per cent at distinction and credit level. There is a scarcity of quality teacher training programs in the country, and teachers rely mainly on

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traditional pedagogies like the lecture method (Tuyizere, 2017). Students resort to problematic and counterproductive learning approaches like rote learning and memorisation of problem-solving steps. Classroom discourses are teacher-centred, and as such, students have difficulty understanding even the basic concepts in physics.

The Ugandan government (UNEB, 2019) has taken measures to enhance science education in secondary schools. For example, consider the Secondary School Science and Mathematics initiative, also known as the SESEMAT project of the Ministry of Education and Sports, done in collaboration with the Japan International Cooperation Agency (JICA). The project's goal is to provide hands-on in-service refresher courses for teachers of science, including physics. Our research aims to supplement these ongoing efforts at the national level to improve the quality of teaching and learning. In particular, we focus on addressing issues about physics education at the high school level (UNEB, 2019). We are exploring ways to transition the mode of instruction from the traditional lecture format towards more interactive practices wherein students have better opportunities to participate and construct knowledge. In other words, our goal is to align classroom instruction with tenets of constructivism. Also, it is practically essential that the reforms we suggest are minimally disruptive of the present situation to be quickly adopted. We agreed to focus on student conception studies, student conception frameworks, and their constructivism compatibility. The impact of physics concept inventories on physics education, the Ugandan educational framework and evaluation system, and lastly, comparing Ugandan studies to CIs are all reviewed through the lens of constructivism.

Several scholars have put forward theories on how students learn in general. Students construct their perception and understanding through their interactions with their environment (Piaget, 1983). Constructivism is a psychology-based learning theory that explores how learners can acquire knowledge and learn. Publications on the construction of constructivism (Bada & Olusegun, 2015; Dagar & Yadav, 2016; Shah, 2019) emphasise that it is a learning philosophy focusing on the premise that learners actively develop knowledge. A perspective towards psychology and education is one in which learners deliberately develop, perceive, and restructure understanding in unique ways. Thus, maintaining that learners are not hollow containers (blank slates/tabula rasas) (Georgiou, 2014) but bring previous experiences and social factors to create new awareness in any given educational situation. Knowledge is actively constructed rather than passively "transferred intact from the teacher's mind to the mind of the learner". As learners enter physics classes, they develop specific ideas that vary significantly from the accepted empirical understanding of the physical universe in general. Alternate conceptions (misconceptions) are found in the prior knowledge of physics learners, the phrase used for commonalities in learner responses to queries of learning that occur throughout courses.

Therefore, the fundamental position underlying constructivism (Smith et al., 1993) is that all research requires the perception of phenomena, circumstances, and events, including teaching in the classroom, from the viewpoint of the present experience of the learner. Education researchers and stakeholders have not suggested that alternative physics conceptions deserve special attention in teaching physics in Uganda. Physics education conceptions may thus influence the identification and cataloguing of alternative physics conceptions in the search for a better understanding of their existence and origin - the underlying patterns of students' reasoning in physics subject areas. The following sections address insights from different pieces of proof literature concerning students' alternate explanations and misconceptions.

A Brief History of Student Conception Studies in Physics

Studying students' pre-instructional conceptions about scientific ideas and values sparked a boom in science education in the mid-1970s, and the field (Duit & Treagust, 2003) is still thriving today. Over the last six decades, developments in existing research have significantly impacted how science and mathematics are taught to a lesser extent. In 1970, Kuhn's study inspired many studies of students' alternative conceptions. Kuhn's revisionary version of science history and exploration of the sociology of schooling influenced many analyses of students' alternate conceptions (Mengistie, 2013). Its influence on the scientist's work piqued researchers' curiosity in how disciplinary expertise taught investigators about the growth of an individual's knowledge (Confrey, 1990). Students' conceptions had all been primarily investigated based on the education levels. A few years later, students' conceptions of a more inclusive nature were considered (i.e., conceptions of science subject areas and the learning process). Studies related to physics topics gained clear superiority over other science subject content fields during the same time of inquiry. Cognitive psychologists often use physics illustrations when researching a science domain (Duit & Treagust, 2003). Second, physics seemed to be more mathematically and scientifically formulated than the other disciplines.

A heavy focus on exploring students' concepts of physics content areas are primarily quoted since the middle of the 1970s in areas such as Mechanics (Force and motion; work, power, energy; speed, acceleration; gravity; pressure; density; floating; sinking). Electricity (Simple and branched circuits; topological and geometrical structure; models of current flow; current, voltage and resistance; electromagnetism; the danger of electricity), Heat (heat and temperature; heat transfer; expansion by heating; change of state, boiling, freezing; explanation of heat phenomena in the particle model) and so on (DiSessa, 1983; Halloun & Hestenes, 1987; McClosky, 1983; McDermott, 1984). Prominent scholars have taken the inter-position since the beginning of science in the middle of the 1970s (and even before that) (Mengistie, 2013). The creation of conceptions in students' minds before instruction and during largely conventional instruction is examined. Students begin formal physics education with ideas about their environment, learn definitions for terms used in physics, and develop techniques to seek answers about how and why objects behave as they do, according to various studies in the physics subject areas. Their mental formations built from physical concepts (Osborne & Wittrock, 1983) differ significantly from that of physicists, posing a significant barrier to studying physics. The word "student conceptions" is often applied to these established structures of student mental views, ideas, interpretations, and descriptions.

Children's science, children's algebra, preconceptions, naive ideas, conceptual primitives, private concepts, alternate perceptions, student conceptions, misconceptions, alternative perceptions, alternative systems, naive beliefs, and alternative systems are all words used to describe the constellations of students' theoretical ideas (Confrey, 1990; Driver, l981; Osborne & Freyberg, 1985). Numerous findings have previously prompted research into students' conception terminologies, showing that learners' experience counteracts with knowledge conveyed in structured teaching, resulting in a complex range of unintentional learning outcomes. Learners bring a complex range of alternative conceptions about natural phenomena and events to formal science instruction, spanning age, skill, gender, and cultural borders. Alternative concepts are tenacious and immune to elimination through traditional teaching techniques. These findings have led academics in these traditions to reject the tabula rasa assumption that students come to class with no preconceived notions regarding the topic before it is taught. The conviction (Confrey, 1990) that these naive theories cannot be easily ignored or replaced by direct instruction.

Since the beginning of the investigations into students' perceptions, several cases have been reported. The empirical evidence shown in the previous paragraphs from the physics domain demonstrate the correctness or uncertainty of students' alternative conceptions. Students form their own opinions on various physics topics based on their daily experiences, and they carry these diverse viewpoints into the classroom during teaching.

Exemplars of Student Conceptions in Physics

Several studies literature studies accept that research on students' conceptions should be taken seriously, emphasising explaining students' perspectives before, during, and after teaching (Smith et al., 1993), rather than building theoretical constructs that link philosophies to learning approaches. A wide variety of terminologies that have been quoted historically are used and used interchangeably to explain students' conceptions that researchers discovered. These terminologies guide student thinking that differs from the widely accepted scientific ideas presented in the classroom and clarified by expert concepts. The following are student conceptions cited in physics studies.

Smith et al. (1993), citing Newtonian mechanics as the most thoroughly studied subject matter, agrees with Clement (1983, 1987) and McCloskey (1983) that the misconceptions of students stem from prior experience. The researchers argue that students' misconceptions have been seen as a consequence of day-to-day interactions in the physical and social environment utilising the sub-domain of force and motion. The prevalence of the "motion implies a force" misunderstanding "is rooted in daily perceptual-motor experiences with pushing and pulling goals" is one of the principal instances cited.

Assumptions of science students in electrical circuits and physics dynamics were analysed using an interpersonal dispute approach to facilitate the development of correct theoretical concepts of dyadic relationships with conventional teaching strategies (Thorley & Treagust, 1987). Perceptions among the introductory tertiary physics students are defined in the documented pre-assessment study. Alternative assumptions about electrical circuits include the electrical current is not the same at all points in the series relationship, that the illumination is not the same for the same light bulbs successively installed along the circuit, and that the sequential current is not the same effect. While the study discovers complex inconsistencies as a body that shifts direction briefly comes to rest, the resultant force is zero, a body in constant velocity travel has little apart from a simple null force acting on it. The resulting pressure on a moving target is any type or at least has a portion of that direction in the direction of movement. Thorley and Treagust (1987) resolved that, regardless of the level of students specialising in physics, it has been observed that a significant percentage of students hold scientifically unrecognised conceptions.

Using psychiatric interviews to explain fundamental electricity principles, Johsua and Dupin (1987) studied the pre-instruction conceptions of learners. In the pre-instruction psychiatric interviews, the analysis found that students retained four concepts that defined how a simple electrical circuit operates. Mechanical contacts are used to describe and express the students' preserved ideas freely. The sophisticated use of the moving fluid analogy in the wires begins with a single-wire idea and progresses to a clashing-current concept and a current propagation concept. The researchers developed that the inaccurate interpretations of students act as the foundation for the actions of reasoning and assessment against specific electricity concepts. Therefore, scientific knowledge is built against these "natural" conceptions to be applicable at all stages of instruction.

Pranata et al., (2017) used open-ended multiple-choice items to uncover in a pre-post interaction the alternative principles of the rotational processes of the learners. The rationale behind open-ended multiple-choice items is that learners can understand the theory but lack adequate explanation to estimate when using closed-ended multiple-choice answers. The study results reveal that students have trouble determining how to calculate the torque of several forces. The alternative concepts shared in the students' responses were the assumption that the forces acting downward have a negative rotational direction while those acting upward have a positive rotational direction. Also, in their research, Kinchin (2012) and Rimoldini and Singh (2005) uphold that learners have problems in the core concepts of rotational dynamics because they are not conscious that it is not only a force that defines an object's rotational motion but also the direction vector. The students' conclusions regarding the resulting force on rotational dynamics thus working students who have difficulty studying rotational dynamics around torque, the moment of inertia, and the rotational dynamics law of Newton.

Misunderstandings of heat and temperature amongst physics learners explore that many learners have different definitions of heat and temperature. Learners are frustrated (Alwan, 2011) because the distinctions between heat and temperature cannot be expressed when terminologies are perceived to be the same stuff. In contrast, many learners have alternate conceptions that heat depends on the object's temperature to see that there would be more heat resources for higher temperature objects. Students have difficulty with the concepts of insulators that prove that unique materials are necessary to keep hot things hot and cool things cool. Alwan (2011), however, confirms that learners can use empirical formulas to solve mathematical problems, but within the context, they do not understand the rules underlying the procedures. In evaluating the principle of thermal equilibrium, learners do not make logical sense when their intuitive logic is based on everyday experience, which is perhaps the only justification for learners' alternative interpretations of heat and temperature.

Some studies investigated the conceptual interpretation of rolling motion among university students through the enrichment of conventional teaching with the cube-cylinder analogy. The comparison provided evidence of analogy-based methods' usefulness to resolve more prevalent stereotypes (Vidak et al., 2018) regarding rolling motion. The Rolling Motion Concept Test (RMCT), containing testing items intended to illustrate physical conditions, tested the pre-and post-treatment concepts of students regarding rolling motion. The major goal of the survey was to determine students' understanding about velocity expectations at various points on the wheel, as well as their understanding of static friction and the factors that produce mechanical energy losses in rolling motion. The study findings suggest that students did not understand the part of the friction force in the wheel's rolling motion. As a result, they offer an alternative theory that a travelling ball loses mechanical energy due to the work of the static friction force. An alternative interpretation of failing to correctly distinguish between a spinning circle at the top and bottom of the wheel rotating the same intervals over a given time between rotational and rolling motion points. Previous studies by Rimoldini and Singh (2005) also found that students have trouble developing knowledge of rolling motion that involves a reasonable method of teaching this subject in introductory physics courses.

In attempts to establish an alternate definition of rotational motion and gravity, a framed item displays a top view of a ball whirled in a horizontal circle, just at the end of a line. The whirled ball is forced to sail radially outward by a "centrifugal force when the rope breaks." the students are advised that at a particular stage, the string breaks and are challenged (Berg & Brouwer, 1991) to sketch the direction the ball is going to take afterwards. Learners' standard answers are based on alternative conceptions of a circular force (or impetus) that gives an object and pushes it to continue on a curved path. And that the rope applies a tangential pull to the ball, causing it to fly away before the string is tangentially broken. The previous study has shown that students' alternative perceptions of a force that often moves in the direction of motion often recur (Gunstone, 1984; Osborne et al., 1983). Furthermore, university students' alternate conceptions of circular motion perceived speed and velocity as the same attribute for an object moving along a circular path (Canlas, 2016). Students interpret terminologies such as velocity, centripetal force, and acceleration to have the same sense while failing to apply their centripetal force understanding.

The alternate perceptions of students are studied and classified in the scientific field of electric potential and electricity (EPE). The students' alternate conceptions in EPE's perceptions are naive mechanics, alternate lateral conceptions, alternative ontological conceptions, p-prim related to Ohm's law, mixed conceptions, and loose thoughts (Dega et al., 2012), yet to be discussed in a later section. Open-ended questions are used to discover the EPE ideas of inexperienced learners through interviews with emphasis on groups of learners. The analysis develops many naive student theories, including i) considering the principle of electric potential as a power, as potential energy, as a current, and as kinetic energy. ii) Considering electric potential as a substance entity and also independently as a charge. iii) The potential of two opposite point charges is null. (iv) The resting expression indicates electrical potential, (v) the potential difference is zero for significant distance-separated charges. (vi) The travelling charges do not have electrical potential energy, and (vii) recognise the potential and charges of identical properties as the same conception. The findings, however, are comparable to those of Galili (1995) and Planinic et al. (2006), who previously found naive conceptions among students. The findings include, “uniform field implies uniform velocity and a charged body containing only one kind of charge” from the conceptions of electromagnetism and Newtonian mechanics and basic DC circuits by learners.

A sign of acceptable study is that assumptions that students have in elementary classrooms can continue in high schools and eventually in university courses, suggesting that education can be immune to beliefs and that conventional learning is not suitable to fix them. Given the proliferation of student expectations that physics teachers strive to overcome, we decided to revisit the framework of misconceptions and the framework of resources, all of which relate to particular facets of constructivism.

Misconception Framework

The misconceptions reflect the constructivist theory that individual learners have a fundamental way of reasoning that their present information structures use to make sense and understand the world (Hammer, 1996). It is an alternative to the simplistic, typically implicit view that learners are “empty vessels,” according to which teaching represents a transition to the students of knowledge from the teacher (or textbook, or presentation, etc.). The central point is that students' previous experience contains very rational conceptions that are not compatible with the understanding of experts. Those learners have images that are “consistent among them,” and “extremely firmly held,” describing some of the empirical processes that expert concepts describe before they are taught expert concepts. However, these conceptions differ from the disciplinary ideas presented in teaching that are currently accepted. As a result, such images fundamentally influence how learners perceive and interpret what they see and hear, preventing a simple exchange of information. Therefore, physics educators need to understand the possible reasons behind these misunderstandings and stay vigilant to provide more effective teaching strategies (Ojose, 2015).

To put it another way, understanding and addressing learners’ perceptions encourages teachers to understand the meaning and aspirations of students while teaching a topic and therefore impact their teaching methods (Murphy & Alexander, 2004). Misconceptions can help students improve by comparing them to their past experiences (Driver & Easley, 1978). Students acquire new concepts due to previous experiences, whether in the classroom or their actual surroundings. Misconceptions interfere with studying professional concepts because of their complexity and incorrect content since they are deep-seated and pervasive, thereby establishing lasting barriers to intellectual comprehension (Minstrell, 1982). Misconceptions about circuits that “adversely affect” rigorous electricity research were examined, according to Cohen et al. (1983). Furthermore, PER (Physics Education Research) literature proves that physicists have stated that misconceptions also lead students to misinterpret classroom laboratory activities and presentations (Hammer, 1996). Therefore, misconceptions suggest that it is not enough merely to inform students or show them that physics teachers must help learners modify or substitute their misunderstanding.

The Resource Framework

The resource viewpoint reflects primitive cognitive elements unique to the content and its dynamic experiences (Meredith & Marrongelle, 2008; Sherin, 2001). Physics resources, content-specific, may be philosophical, epistemological, linked to learning, scientific, or other convictions. A founding tenet is that knowledge units (knowledge elements), which may be both prescriptive and cognitive strategies, are joined together to create broader "structures of knowledge." The information systems are triggered and environmental stimuli such as situational and contextual variables (Wood et al., 2014). Together, the elements of information, systems of knowledge, and structures of control that decide when they are enabled are collectively known as "resources." Tuminaro and Reddish (2007) described resources as all the components of the basic knowledge frameworks in the model, patterns of students, and control systems available to students' thinking about a task in physics. Students learning physics have several unique, relevant resources at their disposal. They are providing both an intuitive and systematic understanding of the natural world and knowledge of physics. Students use an innate knowledge of physical structures and processes that they have learned in their everyday lives to make sense of the natural world.

The first research in this vein was the work on the sense of the process by DiSessa (1993). DiSessa indicates that students build from daily experience an intuitive understanding of the physical mechanism. This intuitive sense of physical mechanism results from the stimulation and association of many neural resources alluded to by DiSessa as phenomenological primitives (p-prims). To convey several critical aspects of these cognitive structures, the name, phenomenological primitives, is used. The term "phenomenological" represents the notion that ordinary phenomena are abstracted from these resources. Closer is stronger; for example could be summarised from the sensation that the closer you are to a fire, the warmer you feel (Hammer, 1996). The term "primitive" represents the notion that the individual frequently uses these resources as though they were self-explanatory, "irreducible and undetectable." For instance, a student who use closer is better may answer, "it just is," wondering why it is warmer closer to fire. DiSessa recognises p-prims at different levels of abstraction and focuses on the irreducibility of p-prims concerning the user.

The strength of associations between various knowledge units and knowledge systems will vary, and learning is perceived as a process of forming "association patterns" (Tuminaro & Redish, 2007). These relevant associations are reinforced, allowing for the creation of higher-level institutions when unacceptable associations are eroded. When a student is having trouble solving a problem, one of the central tenets of the resource framework is that it is seldom that they do not grasp the appropriate science. Instead, the requisite cognitive skills of the student have not been activated. Resources are neuronal constructs with numerous grain sizes that can be in different stages of activation at any given time, which can vary from fundamental to essential elements. They cannot be fixed since their activation is always context-dependent, i.e. a student can exit a resource or shift resources often (Conlin et al., 2010; Richards et al., 2018). The presence of a resource defines a cognitive framework in the minds of students. The rightness of a given resource lies in the context in which cognitive sophistication is activated. There are no incorrect resources in cases where resources are triggered and used productively (Hammer et al., 2005).

The challenge of separating resources from students' neural processes is innate subjectivity (Bing & Redish, 2009). Therefore, students' thoughts are not well-ordered or well-defined, but student logic can often be challenging to synthesise into specific buckets. DiSessa (1993) has previously demonstrated that the cognitive resource settings of a learner's network vary along his/her journey from beginner to expert. A more competent student understanding is reflected as unstructured topological resources identify beginning students and restructured topological resources. Instead of seeing an inappropriate resource as a misconception, the resource model's proponents argue that the student applies ideas that are not ideal for the given problem but can be helpful in a different context. The activation of non-conflicting cognitive resources (Richards et al., 2018) is due to constructive learning processes connecting new information to everyday reality and more formalised concepts of metacognitive understanding and concentration to how this insight relates to updated knowledge.

Students' Conceptions Framework Compatible with Constructivism

Physics educators need to take the alternate and philosophical conceptions that encompass the "errors" of learners seriously, rather than merely conveying the expertise of physicists. The view, however, counteracts the intrusion of misconceptions that teachers' instructions should confront learners with the difference between their misconceptions and the ideas of experts. Because they are so widespread, conceptions of studying physics must require a change away from misconceptions to concepts of experts. This change is often described as a substitution involving creating plausible ideas for experts, replacing current perceptions. Learning entails both the acquisition of technical concepts and the dispelling of common misunderstandings. The belief that removing misconceptions has no detrimental effects because they play no constructive role in learning is present in the replacement perception. This perspective frames research to recognise ideas and instructions aimed at exposing, confronting, and removing them. Because there are numerous grounds to doubt its relevance and completeness (Hammer, 1996), this viewpoint's widespread adoption and application cause concern.

On theoretical considerations, misconceptions oppose constructivism (Smith et al., 1994), which considers that student conceptions are profoundly and essentially distinct from experts, therefore posing a doubt that expert concepts may be built from what. Smith et al. argued on empirical grounds that intuitive reasoning is not as coherent or stable as the perspective of misconceptions. While the philosophy of misconceptions presents a need for conceptual change, from the students' misconceptions to the acceptable conceptions of the expert, Smith et al. (1993) and DiSessa (1993) maintain that the view does not take account of how that change can occur. Conflicts with constructivism, however, cite an idea of student discontinuity and how to develop expert expertise. The perspective of misconceptions ignores productive solutions that could serve as learning experiences by focusing entirely on how student concepts clash with technical concepts. The viewpoint of misconceptions does not offer an account of any valuable resources invoked by learners as an integral component of constructivism.

On the other hand, the resource paradigm emphasises constructivist learning theory, which views students' previous beliefs as cognitive growth mechanisms within a dynamic knowledge interpretation of the world. Instead of explaining concrete faulty conceptions, this theoretical framework seeks to describe the interconnections between separate components of information, stressing knowledge refining and reorganisation rather than replacement as central teaching techniques. The conceptualisation of teaching activities (Hammer, 1996) relies heavily on what an instructor perceives in the comprehension and thinking of students. From the resource viewpoint, though, an instructor will see p-prims, components of information that could lead to expert comprehension. For a physics educator, the primary practical significance is that the resource framework involves modifying, organising and using previous knowledge. The perspective can assist in the description and creation of students' valuable conceptions while avoiding misunderstandings. They are leaving ability in a position that is incompatible with expert understanding. Therefore, helping students advance in the knowledge of physicists, including encouraging the involvement of students in science, cultivating acceptable values in knowledge and learning, and faith in themselves as scientists. The following section presents CIs as instruments that can tap and unveil the students' uninstructed ideas.

Concept Inventories

As we continue to teach physics and observe student thinking, it's interesting taking a look back at the history of concept inventories (CIs) in this section, as well as the central inventories of physics and their significance for physics education.

History of Physics Concept Inventories

Before Concept Inventory (BCI) in post-secondary introductory physics education (Hake, 2011), academic writings illustrate Eric Schocket's technical lecturing journey from 1966 to 2006 using conventional methods for introductory physics courses. Eric Schocket noted that the traditional introductory passive-student lecture courses and the lack of interaction between the physics educators and the combined students were recognised by the lack of culture to establish an entirely passive classroom environment. Furthermore, owing to the lack of student participation, the lectures were arranged, and the students were given pre-masticated material clearly to imitate and apply to problems. They were providing an introduction to conceptual challenges, finding answers on their own. However, the participation of the physics instructor was to help students consider the errors they make when solving logical problems. Besides that, another physics education guru, Arnold Arons (1916-2001), represented the aggressive reality of ignoring the implications of studies that exposed the postmodern exposition of abstract ideas and lines of reasoning to passive listeners (Hake, 2011). But for the minimal number of exceptionally gifted students in the area, learners obtained pitifully low grades in understanding and comprehension. The priority was on the "ordinary student" rather than the "exceptional student."

In 2011, Arum and Roksa applauded previous scholars by demonstrating that while there was a growing percentage of students sent to colleges at substantially higher fees, their gains in critical reasoning (Hake, 2011), complex judgement, and written correspondence were either unbelievably limited or empirically non-existent for a substantial proportion of them. However, the students may have gained subject-specific skills that were not tested for by the college learning assessment. In terms of general intellectual competencies assessed, many college students were correctly classified as academically adrift. The results were humbling and were a cause for alarm as the graduate students struggled to acquire the higher-order cognitive abilities that college students are commonly expected to master. However, Georgiou (2016) suggests that as the precipitation of PER from the wider academic area of science education arose, lessons arose from the Physics Learning Improvement Efforts, and more basic methodological advances appeared. Quantitative and qualitative testing methodologies had to change to satisfy more complex criteria, and for PER, this need centred on the student and included evaluating the impact of instructional progress.

In the last four decades, the physics education improvement attempts have surpassed the conventional introductory physics courses. Marked by inactive student classes, recipe laboratories, and algebraic question exams have been of marginal use in improving students' intellectual comprehension of the subject. The PER community appreciated the idea of designing Diagnostic tests for conceptual understanding in the physics domains. There are numerous names on these diagnostic (Multiple-choice) tests themselves, including surveys, concept tests, concept inventories, and conceptual surveys. Therefore, numerous studies suggest that developed science inventories trace their origins in physics to the mechanics diagnostic test (MDT) and force concept inventory (FCI). The preceding section goes through a few of the CIs developed and their respective fields in physics.

Major Concept Inventories in Physics Education

The FCI's success in the field of physics and resulting educational changes have contributed to the development of CIs in the domains of physics content, such as kinematics, electricity and magnetism, waves and optics, thermal physics, quantum physics, rolling and rotational motion, thermodynamics, heat, and energy, etc. Table 1 (Mashood, 2014) and references therein indicate the analysis analyses major physics CIs that have been thoroughly designed for use in the teaching and learning context. A CI is a research-level multiple-choice method intended to assess the conceptual comprehension of students. Students responding to an instrument (item) can either be done in writing or verbalizing (thinking aloud). Based on typical student stereotypes based on several concepts of the main subject, each item has one correct answer and many incorrect responses, known as distractors (Jorion et al., 2015).

Table1: Partial Compilation list of PER CIs published with their respective number of items, Abbreviations, Purpose, Authors, and Publishing years.

Instrument	No of items	Acronyms	Purpose of the CI	Authors (year)
Mechanics Diagnostic Test	36	MDT	To evaluate the original qualitative, common-sense views of students concerning motion.	Halloun and Hestenes (1985).
Force Concept Inventory	30	FCI	To test the comprehension of the basic concepts of Newtonian physics by students using daily vocabulary and common-sense stray thoughts.	Hestenes et al. (1992)
Mechanics Baseline Test	26	MBT	To analyse the concepts of mechanics.	Hestenes and Wells (1992)
Test of Understanding Graphs in Kinematics	21	TUG-K	To measure the ability of learners to interpret kinematic graphs.	Beichner (1994)
Force and Motion Conceptual Evaluation	47	FMC	To test the comprehension of Newtonian mechanics by students.	Thornton and Sokoloff (1998)
Wave Concept Inventory	20	WCI	To test the knowledge of wave phenomena by students in an applied upper-division physics course on electronics and electromagnetic topics.	Roedel, El-Ghazaly, Rhoads & El-Sharawy (1999)
Conceptual Survey of Electricity and magnetism	32	CSE	To test learners' understanding of introductory electricity and magnetism concepts.	Maloney et al. (2001)
Thermal Concept Evaluation	26	TCE	To test the interpretation and implementation of thermodynamic principles by an introductory college or 3rd-year high school students using typical frameworks that represent the students' conceptions.	Yeo and Zadnick (2001)
Energy and Momentum Conceptual Survey	25	EMCS	For standard introductory mechanics classes, to determine practical comprehension of energy and momentum.	Singh and Rosengrant (2003)
Electronics Concept Inventory	50	ECI	To evaluate the concepts of basic electronic circuits.	Simoni, Herniter, and Ferguson (2004)

Instrument	No of items	Acronyms	Purpose of the CI	Authors (year)
Determining and Interpreting Resistive Electric Circuit Concepts Test	29	DIRECT	To test the comprehension of Direct Current (DC) resistive electric circuits principles by students.	Engelhardt and Beichner (2004)
Rotational and Rolling Motion	30	RRMCS	To test the knowledge of rotational and rolling motion principles usually discussed in a conventional introductory physics course by students.	Rimoldini and Singh (2005)
Brief Electricity and Magnetism Assessment	32	BEMA	To test the contextual understanding of the basic principles of electricity and magnetism among students.	Ding et al. (2006)
Circuits Concept Inventory	43	CCI	Before taking circuit courses, expose student ignorance of circuit theory concepts and assess student gains in the comprehension of circuit theory concepts upon completion of the courses.	Helgeland and Rancour (2008)
Quantum Mechanics Concept Survey	12	QMCS	Measure the efficacy of various teaching approaches in enhancing the practical comprehension of quantum mechanics by students and using those measurements to facilitate their learning.	McKagan, Perkins, and Wieman (2010).
Statistical Physics Concept Survey	7	SPCS	To assess the concepts in undergraduate solid-state physics and statistical physics.	Sharma and Ahluwalia (2012)
Rotational Kinematics Inventory	39	REIKI	In traditional introductory physics settings, test students' comprehension of a particle's angular velocity and angular acceleration.	Mashood (2014)

The Impact of Concept Inventories on Physics Education

Since the 1992 FCI, a successor to the MDT by Hestenes et al., the CIs introduced in PER have been used as role models. Their influence on physics education was intended to promote reform, but even early adopters took two decades to emerge from physics research findings (Hake, 2011). The "early adopters" whose efforts were partially influenced by those CIs cited several reasons for a faster pace of adoption in physics education and other science fields such as engineering. Hoellwarth and Moelter (2011) created an introductory mechanics curriculum that emphasises immersive interaction in a studio setting. The FMCE and FCI were used in the curriculum to demonstrate a significant improvement in the students' academic understanding compared to the regular course.

In introductory mechanics, studies by Deslauriers et al., (2011) found that students' success in logical comprehension and quantitative problem-solving ability improved when they were taught using research-based teaching strategies. The researchers also cited better student attendance, increased interest, and more than doubled learning in the section taught using research-based instruction. CIs are developed as evaluation instruments for student thinking studies that the broader PER society can use to provide a standardised teaching and learning measurement and a simple, off-the-shelf means of assessing teaching practices and curricula. They paved the way for physics curriculum development by including a universal and convincing measure of student understanding that teachers will use to test and increase the effectiveness of their teaching (Deslauriers et al., 2011; Madsen et al., 2017). As a result, the invention of CIs for use in college science classrooms has had a significant impact on how society values and conducts science education and science education research and instruction.

The physics CIs in Table 1 is designed to test the physics understanding of secondary, beginning college and university students. When other metrics such as interviews and observations are mixed with different perspectives on physics, it creates a powerful illustration. CIs are essential assessment tools often used to provide feedback on alternative pre-instruction concepts and assess non-traditional teaching approaches' efficacy. CIs also provide an explicit link between individual items and their regulated ideas and insight into student reasoning by explaining misconceptions and patterns. As a result of constructed CIs, physics students can understand universal assumptions about concepts within a given domain. CIs are not used to calculate systemic change but are indicators of prior knowledge that can help physics teachers adapt lessons to solve actual dominant environmental experiences. These are promising tools for testing learning improvements in the physics curriculum (National Research Council, 2013). They assist physics instructors in understanding what students know. During class, they can do the aspects of a curriculum that work well for students and those that don't and demonstrate how well students achieve the desired learning outcomes. The following section reviews the PER threads relevant to the Ugandan education context.

The Ugandan Education Context

The formal educational structure of Uganda adopts a four-tier educational Framework. Including seven years of primary school (ages 6–12), four years of secondary school (Ordinary level), two years (17–19) of advanced secondary school (Advanced level), and finally tertiary schooling. Each level is examined nationwide, and qualifications are awarded. However, over the past four decades, Uganda has developed and engaged in a range of primary educational policy documents in conjunction with academic inputs to facilitate learning and increase the quality of student outputs in educational institutions in Uganda (Asankha & Takashi, 2011; Mwebaza, 2010). The policy on science education was observed within the Government White Paper on Education of 1992 highlights the potential role of science and technology in enhancing development. Physics, Chemistry, Biology, and Mathematics were made compulsory for ordinary secondary school students under the science policy, which went into effect in 2000. Students had tended to score poorly in science subjects that were previously optional for students in lower secondary (UNEB Report, 2014) since the implementation of science policy in 2000 when science subjects were made compulsory in lower secondary (form 1 to form 4). Lack of science equipment/apparatus, inadequate instructional practices by science teachers, and various other reasons are often attributed to the poor results.

The Ministry of Education, Science, Technology, and Sports launched the In-Service Science and Mathematics Teacher Training Program (SESEMAT) with the Japan International Cooperation Agency (JICA) to address these issues. The SESEMAT program was implemented to help in-service teachers develop a constructive attitude and enhance their lesson delivery. Despite all of the above attempts, students continue to perform poorly in sciences, especially physics, and the number of students pursuing science subjects in the upper secondary has remained unchanged. This has sparked widespread concern about the results of physics and other science courses learned at the secondary school level (O-Level). Via preparation and seminars, various teachers and partners have been exposed to this curriculum to develop better-trained teachers who can impart science and mathematics expertise and skills through hands-on and mind-on exercises in a constructive educational environment. Despite an explosion of trained teachers in the last two decades, the controversy over poor math and science outcomes has persisted year after year. As indicated by the UNEB since 1980, these have prompted considerable public concern about students' poor performance in science and mathematics at the secondary school level (Komakech & Osuu, 2014). This is why we undertook this research, which looks at PER threads important to the Ugandan context and studies that looked at students' conceptions and Concept Inventories. As a result, the growing emphasis on learning success is accompanied by heightened concern for educational assessment's quality and use as a measure of academic quality.

Ugandan Assessment System

Uganda's educational system has been exam-oriented since the 1960s. All the training and learning is based on the completion of final exams. It is sometimes alluded to as "examination coaching". The idea that the progression (placement) of students to another class is based on the outcomes of the students only exacerbates this challenge. Equally, Ugandan educators and students do a lot to prepare for the ending exams (Mwebaza, 2010). This has motivated teachers to teach ordinary and advanced secondary sections to routinely test their students using multiple evaluation tests. During the final exams, learners can memorise the subject material taught to them. Students perform well on final exams because of the subjective, informal, immediate, ongoing, and intuitive assessment techniques. According to Mwebaza (2010), the disadvantage of this method is that students are forced to perform rote memorisation of information and cramming of facts rather than practising problem-solving skills and knowledge creation. Unlike the Ugandan education system, however, research on the conceptions and thoughts of students in PER has acquired momentum in the last four decades (Kaltakçi, 2012). They also appear to develop their views as students systematically learn about the world around them through school education or informally through their daily experiences. Because of such a problem, multiple tests were undertaken to test student's comprehension, and the reviewers have not yet come across studies examining student thinking and understanding within the Ugandan scope.

In Ugandan schools, the present educational testing is primarily in conventional pen and paper examinations. Teachers are distinguished by low levels of expertise in evaluation and teaching and learning (Matovu & Zubairi, 2015; Mitana et al., 2018), which is motivated by "surface" teaching, as well as previous exam papers (UNEB documents). This restricts the estimation and assessment of different bits of intelligence, such as artistic, interpersonal, and intrapersonal talents, imagination, and ingenuity. Allen et al. (2016) have reviewed realistic encounters that show that Uganda's latest evaluations and analyses have failed to evaluate the consistency and relevance of education. The basic fact demonstrates that students are subjected to 2-3 continuing assessment tests and a one-time examination to test the knowledge, qualifications, and competencies learned over several years. The evaluations mainly measure rote learning at the expense of high-order reasoning capability and other facets of deep understanding. This has also attracted a growing interest in educational evaluation (Allen et al., 2016; MoES, 2017a, 2017b), reflecting a need to consider the consistency and importance of learning results to local and international environments that are continuously shifting and developing. Therefore, this indicates that educational assessment in Uganda does not satisfy Ugandans' existing and future needs, nor does it respond to the region's social and economic context.

Exploring the Ugandan Studies towards CIs.

The Ugandan government has boosted secondary school science education standards by training teachers to strengthen their pedagogical methods. As per UNEB (2019), teacher-centred activities rather than learner-centred approaches are the pedagogical methods introduced by the curriculum reform manuals and adopted by teachers in classrooms. The teacher-centred plans have prepared students to address questions rather than train students for logical awareness. Learners have found it challenging to understand essential science principles as stipulated in the curriculum for teaching. A deficit in the practice of continuous assessment in the Ugandan education system was identified (MoES, 2017b). Therefore, it advocated alternate modes of testing that have not yet been used, such as CIs, observations, peer teaching, and multi-teacher rating. These would measure a learner's intelligence in comparison to conventional pen-and-paper tests, which would otherwise be impossible to measure with a single method of measurement. Allen et al., (2016) has further stressed the need to use a range of strategies to accurately assess the features of students and their observations being used to help students develop themselves. This is demonstrated by current government initiatives (MoES, 2017b) aimed at restructuring the approach of Uganda to appraisal and exams to mitigate shortcomings that have impeded the ability of physics teachers to recognise the initial conceptions of the students that they have before the learning activities. This will help educators in physics select the best approach to maximise learning outcomes.

The Contribution of this Research Article to my PhD Thesis

To inform CI developers, as well as participants in scientific investigations, up to touch on the status of their work and their expertise and experiences. It is possible to apply the valuable information from examining this study article on concept inventories' conceptions, history, and impact on the physics education system. The review recognises teacher-centred approaches have prepared learners in the Ugandan environment to address questions rather than train learners for conceptual information and that learners have trouble understanding essential physics concepts as stipulated in the teaching curriculum. It thus reduces the ability for learners to have indispensable answers in their understanding and the teacher's pedagogical skills in the teaching-learning process. Therefore, this research article is a small step in the direction aiming to serve as a bridge by developing a Ugandan context-specific inventory that can recognise learners' alternate conceptions, assess teachers' pedagogical activities, and measure the shift of conception among learners in circular motion. The CI (circular motion inventory) will be structured to trigger students' prior experience deliberately, forcing them to enter their alternative concepts to react to the presented items. Just as importantly, it informs the institution and the context of Ugandan education about the impact of embracing students' conceptions, contributing to the decision of the institutions to support essentials aimed at developing future inventories of concepts. Lastly, the CI (circular motion inventory) will provide a Ugandan example for international use advised by CIs in continuing various educational backgrounds.

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