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A Methodological Analysis for the Development of a Circular-Motion Concept Inventory in a Ugandan Context by Using the Delphi Technique

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Abstract. Concept inventories (CI) constitute a key thread in Physics Educational Research. As such, understanding the methodology and the technique of developing a good CI is essential for all physics teachers. This research aims to develop a circular-motion concept Inventory (CMCI) that is valid in the Ugandan context. To reach a consensus, we used the Delphi technique to collect the data from eleven experts in the physics discipline. These experts were asked to rank each CI item in the inventory, based on the relevant criteria, for assigning a degree of relevance for adoption on a scale ranging from one to four, one being "not relevant" and four being "highly relevant." Because the technique does not require experts to meet face-to-face, they remained anonymous to one another. These experts are provided with structured questionnaires of CI items from the Rotational-Kinematics Inventory (RKI) and Rolling and Rotational Motion-Concept (RRMC) inventories in the first round, in order to adopt items relevant to circular-motion concepts in the Ugandan context. They agreed to use 31 CI items in the RKI and 14 CI items in the RRMC in the second round. The mean and standard deviation of expert replies were analysed by using descriptive statistics. We used the methodological principles of CI creation, in order to create eight CI items to fill in the missing sub-concepts. Therefore, a total of 53 concept items were created. In order to analyse their qualities in a psychometric analysis, these will be evaluated by using field testing and psychometric analysis. Various physics instructors will access the CMCI, because the field testing aims to gauge the level of educational efficacy in their academic and research initiatives.

Keywords: methodological analysis; Delphi technique; circular motion; concept inventory

1. Introduction

Over the last four decades, Physics Educational researchers have focused on expanding the pedagogical toolbox for physics teachers by designing conceptually based evaluation interventions, in order to measure the students' comprehension of physics concepts in various physics domains. The Force-Concept Inventory (FCI) (Hestenes et al., 1992) has inspired many physics and other science education researchers to create concept inventories. These items address the extent of understanding of a given physics domain, in such a way that any student who has been educated in the domain, should take the CI, e.g., CSEM, BEMA, RKI, and so on. The FCI is written with terminologies, and in a sense that students understand, according to Hestenes et al. (1992).

The items in the instrument consist of a description, usually with a diagram and four or five possible answers, as well as alternative concepts. Each alternative or distractor is developed, based on the widely held beliefs about the item concept. The first true "CI" was developed from Hestenes' et al. initial evaluation test over time. Because of its remarkable success in the 1990s, the FCI has been used consistently across various institutions. Its impact on physics education is inspiring, and it sparked the development of several other new CIs in physics and in other STEM fields.

Beginning in the early 2000s, physicists focused their attention on developing several of the CIs in fields. These included mechanics, heat and thermodynamics, electricity and magnetism, optics, quantum physics, electronics, nuclear physics, solid-state physics, and astrophysics, among others, by utilising a variety of methodologies (Evans et al., n.d). These CIs are alternative types of academic tests that mimic the conventional multiple-choice exams in structure, creation, and purpose; but they are fundamentally different from them. Hestenes et al. (1992) distinguished a CI from other traditional tests, by stating that anyone could complete it. It was not intended to evaluate competence levels in the knowledge domain being examined; and it does not measure learners' intellect, but instead it investigates their alternative conceptions. Hestenes et al. (1992) also stressed that CI should be written qualitatively, so that learners would understand, requiring little to no rote learning of any formulas, equations, or factual details contained in the item-constructed course material.

In addition to the FCI, several CIs in various areas of physics have led to educational reforms in physics and other STEM fields. Learners' alternative conceptions are elicited by using the developed CIs. These CIs help teachers gain a better understanding of their students' beliefs and thought patterns. Educators also know their students' previous experiences. According to Savinainen and Scott (2002), CIs may positively influence by providing a clear profile of a student's knowledge, including both the content areas mastered and the areas of uncertainty. CIs help physics educators to better adjust their teaching approach to meet the needs of students, and to concentrate on those areas where the grades are the lowest (Savinainen & Scott, 2002). This can be done by understanding students' alternative conceptions. We aim to create a CMCI that will serve the explicit aims of physics educators by assessing students' conceptual understanding of circular motion and their level of concept mastery. The CMCI would elicit learners' alternative conceptions and contribute to the body of research in developing CIs in the Ugandan educational context. The preceding sections present the scholarly writings and the initial steps, before the methodological procedure of the Delphi technique.

2. Scope of the Initial Scholarly Review – the Methodological Steps in Developing a CI

For all physics teachers, understanding the steps and the procedures of creating a good CI can be a useful skill. Even though different inventory-creation methodologies exist (Lindell et al., 2007), several texts and articles on the development and the design of conceptual tests focus on producing classroom evaluations and educationally applicable instruments on a large scale. We are creating a CMCI that would be educationally valid in the Ugandan physics educational context, and for other countries that adhere to a similar context in this research. Due to the differences in syllabus definitions and terminologies across various educational environments, it must have been developed for wide-scale use, rather than being merely validated. We are well aware of the inventory-creation methodological procedures that encapsulate the systematic steps (Singh, 2011; Mashood, 2014) of creating a reasonable inventory of the concepts. These include designing, administration, evaluation (item analysis), and dissemination of the items to be produced in education, to the degree of acceptable usage.

Furthermore, the suggested methodological stages include a feed-back loop from the analysis to the creation phase, which assists educators in involving students in a student-centred pedagogical way, by asking questions, redesigning and developing items and distractors, in addition to revision.

The study uses a Delphi technique to create the CMCI in the initial stage, a concept area (designing concept items in the identified domain). Lindell et al. (2007) promote the concept by stating that different researchers use different methodologies to construct CIs. They strongly urge developers to take all the steps in the design process, and to publish their procedures, so that the public can decide on the most appropriate use of the methods.

As researchers (Treagust, 1988), we have a starting point for resolving proven misconceptions, and a screening test with multiple choices, which appears to provide a relatively straightforward process. The Delphi technique and its subsequent application in the development of diagnostic tests to interpret and identify students' conceptions in areas of limited scientific expertise have been established by the researchers; and these will be discussed later. The use of specially developed multiple-choice tests (CIs) that analyse learners' conceptual comprehension on a small range of topics has significantly improved physics teaching (Hestenes et al., 1992; Thornton & Sokoloff, 1998). As a result, the Delphi method gathers conceptual items that correspond to the Ugandan Advanced Certificate of Educational (UACE) physics teaching syllabi outlined. The inventory design is predicted within the physics teaching syllabi for circular-motion concepts, described as one of the physics concepts, with which students struggle (Canlas, 2015).

Applying the Delphi technique entails measures, such as recognising the CIs developed, validated, and consistently used. The Delphi technique elicits opinions from experts, in order to achieve a group response (Okoli & Pawlowski, 2004). The Delphi method substitutes confrontation and discussion with a carefully organised, sequential series of individual interrogations, similar to questionnaires.

In the Delphi method, we chose the Rotational Kinematics Inventory (RKI) (Mashood, 2014) and the Rotational and Rolling-Motion Conceptual (RRMC) Test (Rimoldini & Singh, 2005) as questionnaires. As a rationale for their selection, the domain concepts of the two CIs are closely examined, and it was discovered that they differ slightly in content definitions from the Ugandan physics circular-motion concepts taught (National Curriculum Development Centre (NCDC), 2013). In the following paragraph, the RKI and the RRMC are thoroughly examined.

The RKI consists of thirty-nine carefully formulated multiple-choice questions designed to probe students' challenges, misconceptions, or alternate conceptions and to elicit their ill-suited thinking habits in studying physics (Mashood, 2014). Theoretical studies, iterative empirical and analytical investigations, and methodologies, such as the think-aloud protocol, retrospective probing, and semi-structured interviews were all explored in detail, during the construction process.

The inventory has three domains: i) the rotational kinematics of a particle (having nineteen items probing the magnitude of angular velocity, the direction of angular velocity, the magnitude of angular acceleration, and the change in angular velocity, as the particle moves), ii) the rotational kinematics of a particle in rectilinear motion (with seven items investigating the aspects of angular velocity, angular acceleration, equation validity $\vec{v} = \vec{\omega} \times \vec{r}$, linear velocity components, the relation between angular acceleration and centripetal acceleration, and the relation between angular acceleration and tangential acceleration) (Mashood & Singh, 2012a, 2012b), iii) the rotational kinematics of a rigid body revolving around a fixed axis (thirteen items created to test torque, moment of inertia, rotational energy, and rolling-motion concepts) (Mashood & Singh, 2013).

Rimoldini and Singh (2005) created a 30-itemized CI, in order to examine students' comprehension of rotational and the rolling-motion concepts in physics and to evaluate the efficacy of instructional methods to enhance students' understanding. Like the RKI, the RRMC established a set of core methodological principles that encapsulate the development of a CI. The inventory contains eight concepts that are explored in the rotational and rolling-motion concepts. Among the 30 concept items in this inventory, there are: i) moment of inertia (4 items), ii) rotational kinetic energy (4 items), iii) angular speed/velocity (4 items), angular acceleration (5 items), torque (11 items), rolling/relative motion (4 items), rolling/role of friction and other parameters (4 items), and a sliding/tumbling cube on an inclined plane (2 items) (Rimoldini & Singh, 2005).

Since interviews are time-consuming; but they offer an excellent means of probing students' reasoning and their depth of comprehension, only a subset of the students was tested by using this approach. Rimoldini and Singh, on the other hand, claim that well-designed MCQ tests provided to a large number of students, combined with in-depth interviews with a subset of those students, were successful in understanding students' difficulties. The following paragraph describes the circular-motion concepts prescribed within the UACE physics curriculum.

We are interested in the UACE physics curriculum, offered as a specialised subject in the higher secondary education cycle (NCDC, 2013). The NCDC is a corporate autonomous statutory body under the Ministry of Education and Sports (MoE & S) responsible for developing educational curricula for Uganda's primary, secondary, and tertiary institutions. Table 1 shows an extract from the circular-motion concepts produced by Uganda's NCDC for advanced secondary physics students in 2013.

Table 1: Extract of Physics Teaching outline for Circular motion concepts

#	Circular-Motion Concepts	Specific Objectives intended of the Concepts
1	Angular velocity.	Define angular velocity.
2	Expression for angular velocity.	Derive the expression $v = \omega r$.
3	Acceleration and force in a circular motion.	Define centripetal and centrifugal forces.
4	The expression $a = \frac{v^2}{r} = \omega^2 r$.	Derive the expression, $a = \frac{v^2}{r} = \omega^2 r$
5	The motion of a bicycle rider, car round a circular track.	Explain the equilibrium of forces in a circular motion.
6	Forces in a circular track	Identify the forces acting on a car moving around a circular track.
7	Conditions for skidding.	Explain the conditions for skidding by a car, or a cyclist, moving around a circular track.
8	Banked tracks and their advantages	Identify the forces acting on a car moving on a banked track and explain the

	(with or without friction).	advantages of banking a track for racing cars.
9	The canonical pendulum.	Derive the expression $\tan\theta = \dfrac{v^2}{rg}$ for a conical pendulum.
10	Applications of circular motion.	Describe some other applications of circular motion.
11	The motion of rigid bodies (simple treatment)	Explain the motion of simple rigid bodies moving in a circle.
12	Moment of inertia	Define the moment of inertia.
13	Rotational Kinetic energy and distinction between rotational kinetic energy and translational energy	Derive the expression for the rotational kinetic energy of a rigid body about an axis; and distinguish between rotational kinetic energy and translational kinetic energy.

Source: NCDC (2013)

The content of Table 1 is extracted as a guide for comparison with previously established CIs in physics education research. The material offers a more comprehensive guide for physics educators, acting as a foundation for soliciting circular-motion concept items from current Cis, while ensuring objectivity in this scientific investigation. The following section discusses the Delphi technique's methodological approach to this study.

3. The Delphi Technique as a Method for CI Construction

The Delphi technique's phases stipulating its justification for usage, the Delphi questionnaire developed for use by experts; and the criteria by which experts are selected, are included in this paper's methodological approach.

Selection of the Delphi Technique

Since its inception, the Delphi technique has seen a variety of extensions; and it is now used by a diverse range of disciplines (Hasson et al., 2000; Massaroli et al., 2017; Okoli & Pawlowski, 2004; Schmalz et al., 2021). Its use in scientific research to define distinct methodological perspectives has been tremendously valuable to science research, particularly physics educational research (PER). In this context, we could follow the procedures for creating a CI, including reviewing the important content by physics experts, interviewing students, and conducting a free-response questionnaire, similar to those discussed by Mashood (2014) and Rimoldini and Singh (2005).

The results are used to create the first draft, given to a small group of students, as a test. The data from the pilot study are then analysed to determine the initial inventory's validity and reliability. It is from this point that the report is usually revised, in order to produce a final draft for use. We judged the Delphi methodology to be a good fit for the Delphi method's design, implementation, and analysis. It is easy to use, it shortens the process of CI construction, and it does not require advanced mathematical skills (Yousuf, 2007). When the Delphi technique is used as a group response, a consensus is reached with one representative opinion from the physics experts, in order to collect the circular-motion concept items. The questionnaires used in the Delphi technique are presented in the following section.

The Delphi-Technique Questionnaire for Study

Based on a study of the literature, the RKI (Mashood, 2014) and RRMC (Rimoldini & Singh, 2005) feature material that is close to the NCDC's physics teaching syllabus outline for circular-motion concepts in Uganda (2013). We turned the RKI and RRMC into research questionnaires, with their collective concept items. We sent them to experts, who were asked to rate or evaluate each concept item of the chosen inventory by using the criterion of relevance specified by assigning a degree of relevance for adoption. For both inventories, the degree of relevance is determined by using a 4-point Likert scale.

Degree of relevance	Interpretation
1 =	the item adopted is not relevant to the measured concept
2=	the item adopted is somewhat relevant to the measured concept
3=	the item adopted is quite relevant to the measured concept
4=	the item adopted is highly relevant to the measured concept

Within the questionnaires, instructions were included to classify those circular-motion concept items that should be adopted. The participants accomplished this by assigning to each item a degree of relevance. Their evaluation is based on the concept items included within the circular-motion concepts of the advanced physics curriculum's teaching syllabus, with as much objectivity and constructiveness as possible. We focused on the eligibility requirements for physics educators; because this is an essential phase in the process. It directly affects the quality of the results obtained (Hsu & Sandford, 2007).

Criteria of Selection of the Experts

We, as principal investigators in this research study, identified physics educators from the faculty of education, the physics department at the Islamic University in Uganda, and the Kampala International University, as the principal investigators in this research study. Via a "nomination" process, we asked the Delphi study's principal investigators to review, pick, and identify the eligible practising physics educators that are knowledgeable and competent in the physics subject paper. We employed a nomination technique, based on the knowledge-resource nomination worksheet to find the Delphi experts (Chedi, 2017).

We were given physics educators' emails and phone numbers after they were nominated, in order to contact them and meet with them, explaining the Delphi process and requesting them to participate. We made an effort to keep the participants anonymous during the meeting with the nominated physics educators; we avoided dominance influence, thereby allowing for a fast and regulated feedback process.

During the nomination process, we decided that 11 physics educators, who we considered to be experts in this Delphi process, would be an adequate number of experts to participate in the study (Chedi, 2017). The 11 physics experts met the qualifications prescribed in the knowledge-resource nomination worksheet, including i) having knowledge and experience in teaching physics papers, one at UACE for a minimum of 10 years, where circular motion is a sub-topic in that portion of the subject paper; ii) being a physics examiner at the Uganda National Examination Board; iii) having the ability and desire to participate; iv) being ready to devote enough time to the Delphi process; and, v) having strong communication skills (Adler & Ziglio, 1996). Having met the selection criteria, we agreed that the nominated experts should have a deep understanding of mechanics, despite their busy schedules of teaching, testing, marking, and scouting at the national level. The following section analyses the Delphi technique's findings in phases.

4. Analysis of the Delphi-Technique Findings

Expert responses were analysed quantitatively, whereas the students' responses were taken to be qualitative. The findings were examined in three phases. The results of the first round of the Delphi technique were analysed in phase one, while the findings of the second round of the Delphi approach were analysed by using the descriptive statistics in phase two. Interviews with the students were done in the third phase, in order to design distractors for the items constructed. Finally, the third round was utilised to create the missing sub-concepts that were not present in the inventories used to develop the expert questionnaire.

Phase I of the Delphi Technique towards the construction of CMCI.

Each expert got two questionnaires (RKI & RRMC) in round one of the Delphi processes. They were asked to rate each item by using the relevant criteria, based on the instructions provided. Only 11 of the 11 experts who committed to take part in the study followed through on their promises. We used the IBM SPSS Statistics Version 21 to code all of the responses and to examine the average scores, in order to find those items that warranted more than the average score, as determined by the experts (Table 2).

Table 2: Descriptive Statistics of the Phase I Evaluation of RKI & RRMC items.

Questionnaire Items of RKI	N	Mean	Std. Deviation		Questionnaire Items of RRMC	N	Mean	Std. Deviation
RKI01	11	2.8182	0.98165		RRMC01	11	3.5455	0.68755
RKI02	11	2.0000	1.18322		RRMC02	11	2.5455	1.21356
RKI03	11	2.7273	0.90453		RRMC03	11	3.4545	0.68755
RKI04	11	3.6364	0.50452		RRMC04	11	3.0909	0.83121
RKI05	11	2.5455	1.12815		RRMC05	11	2.7273	1.00905
RKI06	11	2.6364	1.12006		RRMC06	11	2.9091	1.37510
RKI07	11	3.8182	0.40452		RRMC07	11	2.7273	1.42063
RKI08	11	3.9091	0.30151		RRMC08	11	2.8182	1.32802
RKI09	11	3.3636	0.92442		RRMC09	11	1.8182	1.07872
RKI10	11	3.6364	0.67420		RRMC10	11	2.1818	0.87386
RKI11	11	3.6364	0.50452		RRMC11	11	2.0000	1.09545
RKI12	11	3.8182	0.40452		RRMC12	11	2.0909	1.13618
RKI13	11	3.7273	0.46710		RRMC13	11	2.4545	1.12815
RKI14	11	3.6364	0.50452		RRMC14	11	2.0909	1.13618
RKI15	11	3.7273	0.64667		RRMC15	11	2.0909	1.13618
RKI16	11	3.6364	0.50452		RRMC16	11	2.7273	1.27208

RKI17	11	3.8182	0.40452		RRMC17	11	2.1818	1.25045
RKI18	11	3.4545	0.93420		RRMC18	11	1.8182	0.98165
RKI19	11	1.2727	0.64667		RRMC19	11	2.0000	1.09545
RKI20	11	1.0909	0.30151		RRMC20	11	2.6364	1.12006
RKI21	11	1.2727	0.64667		RRMC21	11	2.6364	1.20605
RKI22	11	1.3636	0.50452		RRMC22	11	2.5455	1.29334
RKI23	11	1.3636	0.50452		RRMC23	11	2.1818	1.32802
RKI24	11	1.3636	0.50452		RRMC24	11	2.4545	1.12815
RKI25	11	1.4545	0.68755		RRMC25	11	2.3636	1.20605
RKI26	11	3.7273	0.64667		RRMC26	11	2.4545	1.03573
RKI27	11	3.0909	1.04447		RRMC27	11	2.4545	1.21356
RKI28	11	2.9091	1.04447		RRMC28	11	2.4545	1.21356
RKI29	11	3.0909	1.04447		RRMC29	11	3.0000	1.26491
RKI30	11	3.3636	0.80904		RRMC30	11	2.5455	1.12815
RKI31	11	3.4545	0.82020					
RKI32	11	3.4545	0.82020					
RKI33	11	3.3636	0.67420					
RKI34	11	3.1818	0.87386					
RKI35	11	3.6364	0.67420					
RKI36	11	3.4545	0.68755					
RKI37	11	2.8182	0.87386					
RKI38	11	3.5455	0.68755					
RKI39	11	3.1818	0.87386					

We used a descriptive statistical range interval for the 4–point Likert scale (Taherdoost, 2019) to select items that did not merit, based on the replies from 11 participants for phase 1 in Table 2. The Likert scale was chosen, because it is simple to create and to produce a highly reliable scale; and it is straightforward for participants to read and to complete. As shown below, we used a Taherdoost Likert scale to compute and evaluate the experts' assessment of the degree of relevance of the items in circular-motion concepts from the questionnaires.

Interval	**Interpretation**
1.00 – 1.75	Not Relevant
1.76 – 2.50	Somewhat Relevant
2.51 – 3.25	Quite Relevant
3.26 – 4.00	Highly Relevant

There are 39 concept items in the first questionnaire that contain RKI concept items. Table 2 shows that the questions numbered RKI02, RKI19, RKI20, RKI21, RKI22, RKI23, RKI24, and RKI25 had average scores below 2.51. The questions in the RKI questionnaire that did not have scores above the recommended average for adoption in the CMCI are in a sub-domain describing a particle travelling in a straight line (i.e. RKI19, RKI20, RKI21, RKI22, RKI23, RKI24, and RKI25).

Thirty-one of the RKI's 39 questionnaire items had average scores, with a fairly relevant interpretation; therefore, they are evaluated, in order to be adopted. Secondly, the RRMC research questionnaire, consisting of 30 questions, was examined. RRMC09, RRMC10, RRMC11, RRMC12, RRMC13, RRMC14, RRMC15, RRMC17, RRMC18, RRMC19, RRMC23, RRMC24, RRMC25, RRMC26, RRMC27, and RRMC28 are the RRMC questionnaire items that did not score beyond the average score to be adopted in the CMCI (Table 2). The CMCI includes the RRMC's remaining fourteen questionnaire items, with an average score greater than 2.51. A combination of 31 items from the RKI questionnaire and 14 items from the RRMC questionnaire have been used to create the CMCI 45 items. In the second phase, the 45 items in the questionnaire were to be evaluated.

Some of Uganda's NCDC's circular-motion concepts for UACE physics students in 2013 did not appear in the two Delphi questionnaires used. The motion of a bicycle rider, a car around a circular track, forces in a circular track, and conditions for skidding, as well as banked tracks and their advantages, are the circular-motion concepts of concern (with or without friction). The experts are concerned about the questionnaire items' coverage from the two questionnaires during phase I of the Delphi process. This fear is well-founded, and well-observed. Because it requires a procedural and a methodological approach, we addressed this concern in the third phase of the Delphi process.

At an early-item production stage (Pre-Delphi generative phase for phase III), we asked the experts to create fifteen multiple-choice questions for the sub-domain, and to draft the CI items sent to the Delphi participants for review and revision, as needed. Because no multiple-choice survey on those circular-motion concepts has been established, we developed concept items in this procedural manner. The following section examines the outcomes of the phase I's review.

Phase II of the Delphi Technique towards the Construction of CMCI

Each Delphi participant received a second questionnaire in the second phase, which asked them to rate the relevance of the questions, based on the information supplied in the first phase. We used a controlled mechanism of communication for experts to get feedback on their thoughts, as expressed in phase I (Massaroli et al., 2017). They were asked to revise their opinions and to respond to the ideas expressed by other experts. This enabled a consensus to be achieved about those circular concepts that were to be tested at the end of the phase rounds.

The second phase is an iterative procedure that collects and distils the experts' opinions from phase I. The second phase includes a follow-up questionnaire, based on the results of the first-phase surveys. We're no longer talking about a questionnaire, as an iterative instrument, but rather a CMCI Zeroth draft. The iterations of the zero draft CMCI could end, when the experts have reached a consensus on the circular-motion items acquired, and when theoretical saturation has been attained (Skulmoski et al., 2007). The replies were coded again in IBM SPSS Statistics Version 21, in order to analyse the average scores and to identify those items that warranted a higher score than the average (Table 3).

Table 3: Descriptive Statistics of the Phase II Evaluation of the Zeroth draft of CMCI

Items of Zeroth CMCI	N	Mean	Std. Deviation		Items of Zeroth CMCI	N	Mean	Std. Deviation
CMCI01	11	3.3636	0.67420		CMCI24	11	3.4545	0.82020
CMCI02	11	2.5455	1.21356		CMCI25	11	3.0909	0.83121
CMCI03	11	3.4545	0.68755		CMCI26	11	3.3636	0.80904
CMCI04	11	4.0000	0.00000		CMCI27	11	2.5455	1.36848
CMCI05	11	3.4545	0.68755		CMCI28	11	3.5455	0.93420
CMCI06	11	3.7273	0.46710		CMCI29	11	3.0909	0.94388
CMCI07	11	3.9091	0.30151		CMCI30	11	2.8182	1.16775
CMCI08	11	4.0000	0.00000		CMCI31	11	2.4545	1.29334
CMCI09	11	3.9091	0.30151		CMCI32	11	2.5455	1.12815
CMCI10	11	3.7273	0.46710		CMCI33	11	3.0000	1.09545
CMCI11	11	3.6364	0.50452		CMCI34	11	3.0000	1.09545
CMCI12	11	3.6364	0.67420		CMCI35	11	3.2727	1.27208
CMCI13	11	3.6364	0.50452		CMCI36	11	2.9091	0.94388
CMCI14	11	3.2727	1.00905		CMCI37	11	3.0000	1.09545
CMCI15	11	3.5455	0.52223		CMCI38	11	3.0909	1.04447
CMCI16	11	3.7273	0.46710		CMCI39	11	3.0000	1.09545
CMCI17	11	3.8182	0.40452		CMCI40	11	2.8182	1.16775
CMCI18	11	3.6364	0.50452		CMCI41	11	3.2727	1.10371
CMCI19	11	3.6364	0.50452		CMCI42	11	2.9091	1.04447
CMCI20	11	2.7273	1.10371		CMCI43	11	3.1818	0.98165
CMCI21	11	2.7273	1.10371		CMCI44	11	3.3636	1.02691
CMCI22	11	3.1818	0.87386		CMCI45	11	3.0000	1.00000
CMCI23	11	3.6364	0.50452					

We computed the descriptive statistics of the average scores and of the standard deviation for each zeroth CMCI item, based on the replies from 11 experts for phase II, as shown in Table 3. Except for one item, the average scores for all the Zeroth CMCI items were stabilised by phase II. In the previous literature on the optimal number of rounds (stages) in Delphi investigations, the researchers tended to settle on a varying number of rounds, based on their intended level of consensus (Chedi, 2017).

Some researchers feel that this should be done until an agreement is reached; while others say it should be done in two to nine rounds, with three being the most common. We agreed that only CMCI31 had a mean of less than 2.51 out of the 45 Zeroth CMCI items to be discarded, resulting in 44 CMCI items being retained. The number of iterations in the iterative process varies, depending on the exercise's nature, purpose and group. Homogeneous groups always use two iterations to achieve the more accurate and consistent Delphi results (Hasson et al., 2000). Nonetheless, we agreed on the two iterations in this context, with the reasoning of taking into account the participants' weariness, the nature of the study, the attrition rates, the time, and the expense of going from one expert to another.

The experts' findings on the development of the missing CIs are discussed in the next section.

5. Phase III of the Development Strategy towards the Construction of CMCI – Construction of Missing-Concept Items.

Round 0

Instead of creating items from scratch, from an inventory identified as lacking, we decided to streamline the process. We tasked the experts to develop a list of three multiple-choice questions (MCQ) on each circular-motion concept, which students usually misunderstand, as mentioned in the pre-Delphi generative phase for this phase III. Creating functional "distractors" for multiple-choice answers in terms of their expertise in the teaching service, is critical in designing good CIs. The 15 MCQs were created by using the following concepts: bicycle rider motion, a car around a circular track, forces in a circular track, conditions for skidding, and banked tracks and their advantages (with or without friction).

Each of the 11 experts that took part in the Delphi procedure, provided 15 multiple-choice questions. The developed MCQs were received and compiled into a master list of 17 concept items unique in their structural construction. At the same time, similar, confusing or deceptive, and inappropriate items for future inventory, were discarded. The goal of revising the number of created concept items was to eliminate any repetitions and make the document more legible, precise, and comprehensive.

After establishing the initial concept questions, we amended the list to improve the question-to-concept mapping. A master list of 17 concept items was compiled; the concept items were readability-rated, before being used as the foundation for the next phase.

The Readability Evaluation

Because of the widespread usage of grade-level readability assessment (Calderón et al., 2006) in school textbooks, we employed readability evaluation, as one of the strategies utilised to assess the students' readability for reading and comprehension. We examined the sub-domain content, the structure, the writing style, the layout, and the design, while evaluating the MCQs generated. One of the characteristics supporting the reading was measured by using the Flesh-Reading Ease Formula (FRE), which is extensively used to analyse survey readability integrated into Microsoft Word for computer-Windows programs. The number of words per sentence in a text impacts the difficulty level, when the readability rating is computed by using a computerised formula.

The average word length and the sentence length are the best determinants of a text's readability and appropriateness (Meade & Smith, 1991). The 17 MCQs prepared in Microsoft Word for Windows were completed, and the readability statistics report of 64 per cent was disclosed by using the FRE formula. The MCQs are judged as standard and easy-to-read and understand, with 64%. Calderón et al. (2006) concurred that a score of 60 to 70 would be adequate for determining the readability of an item (instrument) when using the FRE method. After rating, the 17 MCQs were discussed in round 1.

Round 1
The 17 synthesised concept items were put into a questionnaire structure and sent to each expert in round 0, using the Delphi process guidelines to score each concept, based on how crucial it is for a learner to understand the concept. For each MCQ, we used a scale based on Taherdoost's (2019) Likert scale, in order to assess the experts' perceptions of which concepts were not essential to know, and which are crucial to understand. Eleven of our expert participants ranked these 17 MCQs. The mean scores and the standard deviations derived for each MCQ from the synthesised 17 concept items in round 0, were computed and analysed by using the IBM SPSS statistics version 21.

Furthermore, the goal of this round was for experts to reach fundamental agreement on the concepts in the created MCQs. Numerous MCQs were made, but experts had to agree on the MCQs developed repeatedly and deemed relevant to have a credible instrument. The MCQs concern bicycle-rider motion, a car rounding a circular track, the forces acting on such a car, and their application. When verified in the physics education community, these are intended to be comprehensive enough to allow for long-term usage of the CI items.

Table 4: Descriptive Statistics of Phase III synthesised Concept Items

Circular Motion Concepts	Synthesised Items	Mean	Std. Deviation
The motion of a bicycle rider, car round a circular track (with or without friction)	MCQ101	3.8543	0.64742
	MCQ102	2.3925	1.22134
	MCQ103	2.9251	0.91646
	MCQ104	2.5621	1.03351
	MCQ105	1.3636	0.32195
	MCQ106	1.3872	0.42156
	MCQ107	3.2353	1.11321
Forces acting on a car on a banked track	MCQ208	1.6127	1.10213
	MCQ209	1.1641	0.00221
	MCQ210	2.5281	1.31413
	MCQ211	3.4057	0.00216
	MCQ212	2.5352	1.01435
Application of circular motion	MCQ313	1.2745	1.45895
	MCQ314	1.7449	0.57442
	MCQ315	2.6044	0.76765
	MCQ316	1.2754	0.88533
	MCQ317	1.0556	0.34716

Table 4 shows the mean scores of the 17 synthesised concept items. Eight MCQs had a mean score higher than the standard of 2.51. MCQ101, MCQ103, MCQ104, MCQ107, MCQ210, MCQ211, MCQ212, and MCQ315 were the questions (Appendix 1). Discarded MCQ items were those with mean scores less than or equal to the necessary norm. In the second round, we agreed to interview students by using the eight MCQ items. Because any distractors may need to be updated, in order to reflect the changing students' perceptions; and the following round's interview sessions were regarded as being significant.

Round 2
Delphi experts, who are physics educators with extensive experience of teaching physics in advanced secondary schools, were tasked with creating MCQ items. For each MCQ item, a total of four options were developed. One is a correct response, while the other three are distractors, based exclusively on experts' opinions. However, the distractors in the MCQ items are also found in students' alternative thinking. Furthermore, one of the FCI's strong characteristics is that the MCQ distractors are based on typical students' alternative briefs (Hestenes et al., 1992).

This logic enabled us to conduct interviews in five secondary schools, with students offering physics at the UACE. Unfortunately, this is a challenging endeavour because most physics educators, including the authors of this study, have little understanding of what happens in students' thoughts when they engage with circular-motion concepts. As a result, in addition to the proposed methodological steps, this one is critical, as it entails a process of developing open-ended question items from the 8 MCQs, which we used to interview the students in small groups of two, in each of those schools (Ding et al., 2006; Mashood, 2014; Mashood & Singh, 2013, Rimoldini & Singh, 2005).

We better understood the students' cognitive processes, due to our interactions with them, which helped us to create effective distractors. We invited the students to think aloud, as they responded to the questions included in the interview-response section ahead.

6. Interview Responses to Free-Response Items by Students

As indicated in Round I, we decided to interview the students by using the 8 MCQ items in this round. The concept items that arose were the motion of a bicycle rider, a car travelling around a circular track (with or without friction), the forces acting on a car on a banked track, and the application of circular motion (Table 4).

The interview questions are phrased in such a way that they examine the students' alternative conceptions. Like the concepts in Table 4, we interviewed students. Firstly, i) a car negotiating a curve, ii) a small car and a large truck travelling around the icy banked curved road at the same velocity, iii) when a car is driven around a horizontal curve too fast, and the car starts skidding, iv) incidents encountered for the car to overturn, when driven on a horizontal circular track.

Secondly, i) a force causes a vehicle to follow the radial direction, while driving on a banked circular track; ii) a force that causes a car to follow the circular path while driving on a flat, curved road, and identifying which direction depicts the net force acting on the car rounding a very steep hill at a low speed. Thirdly, i) students' conceptions about an inelastic string attached to a stone rotating in a horizontal plane of increasing velocity breaks. To enable us to update and develop successful distractors, we reviewed all of the students' interview responses and explanations. In the preceding section, only one of the five student groups examined was provided, as a sample of their responses.

Interview Responses of the Students

1) *Interviewer:* when the car negotiates a curve, the vehicle's passengers are thrown outwards, but the cyclist bends inwards, while negotiating the same curve. Explain why this always happens?

Group 1 of Students:

…………… [looking at each other] ……[one of them responds]…… since the car has four tires, so when it is negotiating a curve, the reaction will be concentrated onto one side of the vehicle, consequently throwing the passengers onto the other side. But ………… [Pausing and thinking] ………… for the cycle … it has two wheels, so the cyclist has to bend to reduce the reaction force. ……… [Colleague supplements] …. The car is heavier because it has people in it; and when reaching the curve, the driver always reduces the speed.

Interviewer: which reactionary force is it that you are talking about?

Group 1 of Student: …… It is the frictional force.

2) *Interviewer:* A small car and a large truck travel around the icy banked curved road at the same velocity without slipping. The small car with a mass, m, negotiates the curve. What will happen to a big truck with a load of tons, if it also negotiates the same road?

Group 1 of Students:

……. The big truck tends to slide down towards the inside of the curve.

Interviewer: why does it happen that way?

Group 1 of students: ……… [Asks the colleague if he can explain] ……… because of centripetal force.

3) *Interviewer:* When a car is driven around a horizontal curve too fast, and the car starts skidding. Which incidents explain such a scenario?

Group 1 of Students: ………… When the car is moving, the vehicle becomes too light; therefore, it has to skid.

Interviewer: Asked the colleague do you agree with the answer given?

Group 1 of students; ……. No………

Interviewer; why a no?

Group 1 of students: ………… [Pauses a little thinking]…….. for me, I think ….. that when the car is moving, the engine is moving in a straight line, therefore it is not turning as the vehicle is turning.

4) *Interviewer:* On a horizontal circular track while driving a vehicle (the interviewer pictures a car moving on a horizontal curved road). What incidents are encountered to make it possible for the vehicle to overturn?

Group 1 of Students:

……….. [The students observe the picture, as they discuss] ………. [One of them speaks] …. We think there is a high friction on the ground; and this causes the wheels to oppose the frictional force.

Interviewer: I did not understand you when you said that the wheels oppose the frictional force? Could you please add more insight?

Group 1 of students: ………… [Pauses a little, while thinking] ………….. I was saying ….. when the car is turning, the frictional force is high because of the brakes being applied, which reduces the reaction on the ground, hence causing the car to be thrown outwards.

5) *Interviewer:* Consider a car being driven on a banked circular track. Which force causes the vehicle to follow the radial direction at the constant speed of the banking angle, as it travels through a banked-circular curve and why?

Group 1 of Student:

……………. Because while moving in a circular curve, centripetal force is applied to the body; and when the weight is also light, the body will continue moving due to acceleration and due to gravity.

Interviewer: You talked about a body; which body are you referring to?

Group 1 of the students: I meant the body of a car. ……………. [The other student added]…….. Since the vehicle is moving at a constant speed, it will continue moving in the same direction.

Interviewer: Which direction is the vehicle moving in?

Group 1 of the student: ………….. the direction of motion

6) *Interviewer:* Consider a car driven on a horizontal curved road, going around a circular curve at a constant speed (the interviewer had a picture of a vehicle moving on a flat, curved highway). What force causes it to follow the circular path and why?

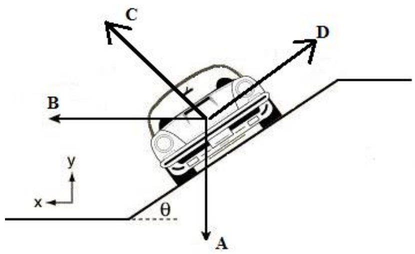
Group 1 of Students:

……. It is the acceleration due to gravity and the weight of the car.

Interviewer: Why those forces?

Group 1 of students: ………. [Pauses and thinks] …… because the acceleration due to gravity will pull it towards the road.

7) *Interviewer:* A car rounds a very steep, sloping curve at a low speed. A front view of the car is shown (the illustration was on paper that the interviewer showed the students). Which direction depicts the net force acting on the car for the situation shown in the figure, and why?



Group 1 of students: ….. (Discuss between themselves for a response) …………….. They agreed together that the net force is in the D direction.

Interviewer: Why would you think it is in the D direction?

Group 1 of students: …. (One of them responds) ………….. Because when a car is moving in a circular curve, the point of view is seen correctly on the opposite side.

8) *Interviewer:* One end of an inelastic string is attached to a stone. The string is rotated in a horizontal plane of increasing velocity, retaining the other end (the interviewer demonstrated a string whirled in a horizontal circle with a stone attached). Why does this break at any speed?

Group 1 of Students:

The students observed the demonstration ……………… (Pauses and thinks) …….the elasticity keeps increasing until at a certain point it breaks.

One looks at the other gesturing if the answer was given right ….. [Colleague smiles supplements saying] …….. because even if the person holding the string ……… the string will keep moving and this increases the tensional force due to the weight of the stone being high, thus causing the string to break.

These two-student interview sessions aimed to update the expert opinions on the distractors for the MCQ items, and to develop effective functioning distractors. Based on their historical and current understandings of the existing phenomena gathered from their spontaneous responses to the interviews, this methodology uncovered the prevalent students' misconceptions that constitute the distractors. The three distractors for each question are derived from the misconceptions identified during the interview sessions. The distractors have been defined as the incorrect replies that commonly appeared as responses to the interview questions used to probe the students.

As a result, the most common erroneous responses across the five groups create distractors for each MCQ item.

7. Conclusion

Physics experts agreed to adopt 31 CI items for the RKI and 14 CI items for the RRMC using the Delphi technique. The motion of a bicycle rider, a car around a circular track, the forces acting on a vehicle on a banked track, and the application of circular motion are among the 8 CI items of circular motion concepts developed by employing the methodological principles of CI development. In Ugandan education, we now foresee roughly 53 concept items addressing the circular motion concepts in total. These 53 concept items will serve as a pool for us; and we shall be selecting from them. We intend to have three concept items on average's and to develop an inventory that the students can reply to in 1 hour.

If the students request extra time, the time restriction will not be strictly enforced. A 53-item test will be administered to as many students as possible from various secondary schools, with the results subjected to psychometric analysis. As a result, the pilot's research findings and the psychometric indices analysis of the concept items will be used to evaluate the final items included in the final CMCI. After achieving the pilot goal, many physics educators will use the CMCI in their own instructional and research undertakings. The content scope of the study is confined to two CIs and to the Ugandan educational setting.

As a result, this study is a modest start towards constructing a Ugandan context-specific inventory to identify the learners' circular motion alternative conceptions, in order to assess the teachers' pedagogical practices, and measure the learners' shift in conception.

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Appendix 1: Constructed Concept Items

MCQ101). The passengers are thrown outwards when the car negotiates a curve, but the cyclist bends inwards while negotiating the same turn. What happens, since

(a) The car is heavier than the cycle, so the centripetal force pushing into the centre is absent from the process.
(b) The cyclist counteracts the centrifugal force, which always throws out the passengers in the car.
(c) While the car has four, the cycles have two wheels, so there is little friction.
(d) The cyclist counteracts the centripetal force that pulls the passengers to the centre of the curve in the car.

MCQ103). A small car and a large truck travel around the icy banked curved road at the same velocity, v. without slipping, the small car with a mass, m, negotiates the curve. During the negotiation, what will happen to a big truck with a load of several tons?

(a) Since the frictional force will be less on which to stand, the big truck cannot climb the icy banked curved path.
(b) It tends to slide down towards the bottom of the icy banked curve road curve, as claimed.
(c) Due to its weight, the big truck will have to topple.
(d) Without sliding, the big truck will still negotiate the curve.

MCQ104). When a car is driven around a horizontal curve too fast, and the car starts skidding, which of the following precisely explains such a scenario?

(a) The engine of a car is not powerful enough to prevent the vehicle from being pushed out.
(b) There is inadequate friction between tires and the road to keep the car in a curved direction.
(c) To make the turn, the car is too heavy; since the car's weight exceeds what is required of it, the centripetal force is weaker than the car's force.
(d) When the car moves, the engine is also moving in a straight line, thus not turning as the vehicle is turning.

MCQ107). On a horizontal circle track, while a vehicle is being driven, as shown in Figure A. 1, what incidents are encountered to make it possible for the car to overturn?

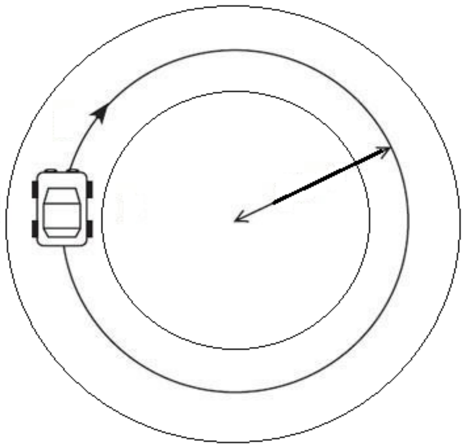

Figure A: 1. A car on a horizontal circular track

(a) The inner wheel that leaves the ground first will fall outside the base, thus the line of action of its weight.
(b) The outer wheel that leaves the ground first will fall outside the base, thus the line of action of its weight.
(c) The wheels both leave the ground concurrently, taking the tangent line to the circle.
(d) Either the inner wheel or the outer wheel leaves the ground because of the high level of friction on the ground.

MCQ201). As seen in Figure A: 2, while a car is driven on a banked circular track, what force causes a vehicle to follow the radial direction at the constant speed of the banking angle, as it goes through a banked circular curve?

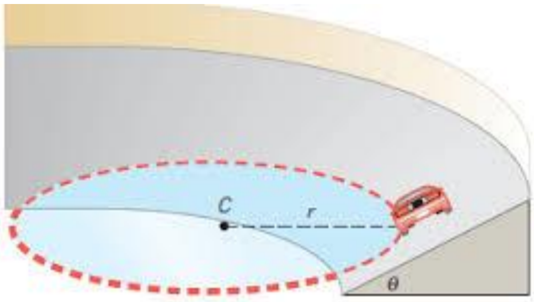

Figure A: 2. A car on a Banked track

(a) If the banking angle is appropriate, the force of friction from the road would be used.
(b) Since the car is moving, it feels the acceleration that would help it follow the circular track due to gravity and the weight of the vehicle.
(c) A normal force that is perpendicular to the surface of the road.
(d) No force allows the car to do this, when the car drives at a constant speed, and there is no acceleration in the circular banked direction; and thus, it can continue to operate.

MCQ211). When a car goes around a circular curve at a constant speed on a horizontal curved road, what force causes it to follow a circular path?
(a) Due to the gravity and the weight of the car, the acceleration pulls the car towards the road.

(b) The force of friction between the tires and the road causes a circular path to be followed by the car.
(c) The normal force from the road will keep the car following the circular path.
(d) The force exerted by the engine allows the car to do this when the car drives at a constant speed, and there is no acceleration along the horizontal circular direction; and thus one can continue to drive.

MCQ212). A car rounds a very steep, sloping curve at a low speed. To the right, a front view of the car is shown in Fig A: 3. Which direction depicts the net force acting on the car for the situation shown in the figure?

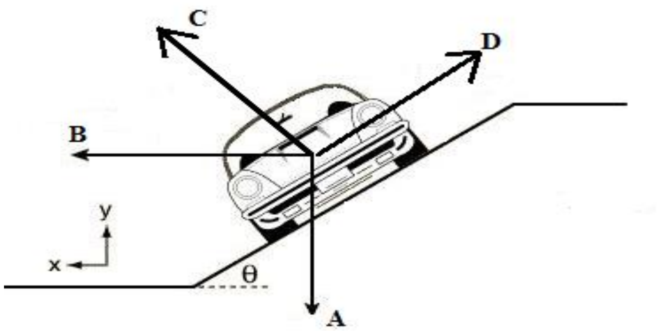

Figure A: 3: A front view of a car on a banked Track

a) A (b) B (c) C (d) D

MCQ315). One end of an inelastic string is attached to a stone. The string is rotated in a horizontal plane of increasing velocity, retaining the other end, as shown in Figure A. 4. At any speed, it breaks because:

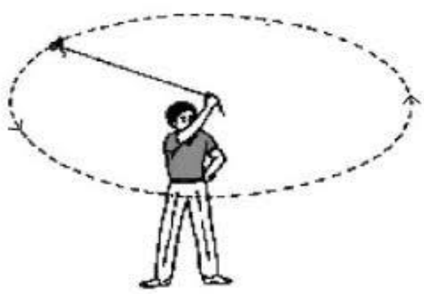

Figure A. 4: A stone whirled in a horizontal plane attached to an inelastic string

(a) The earth's gravitational force is stronger than the tension in the string.
(b) The centripetal force provided is greater than the tension exerted by the string.
(c) Less than the tension in the string is the requisite centripetal force.
(d) The centripetal force is greater than the stone's weight.