CONCEPTUAL UNDERSTANDING OF NEWTONIAN MECHANICS AMONG AFGHAN STUDENTS

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Abstract
In this paper, the level of conceptual understanding of Newtonian mechanics among Afghan school and university students in Kabul, Afghanistan was investigated. This study employed a quantitative descriptive survey method where the Pashto version of the Force Concept Inventory (FCI) was given to a random sample of 216 students from two schools and 90 students from two universities in Kabul city. The collected data were analyzed using SPSS v.24 and Microsoft Excel, where descriptive and inferential statistical analysis methods were used to determine the students' level of conceptual understanding in Newtonian mechanics. The results of this study revealed that generally, Afghan students had a low level of conceptual understanding of Force which is less than the Newtonian entry threshold for FCI. The results further showed that there is a significant difference between school and university students in the level of conceptual understanding. Furthermore, the results indicate that student's gender didn't have any significant effect on the FCI scores of university students. In general, the results confirmed that both school and university students were having difficulties to conceptually understand Newtonian mechanics. Therefore, the results of the study can be added to the database and serve as a guideline for teachers and students to increase their conceptual teaching and learning. In addition, it can be used to correct the students' misconceptions and to improve teaching and learning of physics in Afghanistan.
Keywords: Pashto version of the 1995 FCI; Conceptual understanding of Newtonian mechanics; Students′ performance and Newtonian entry threshold.

INTRODUCTION

In the teaching and learning process, it is important to know about students' understanding of a concept. Without good basic knowledge, students will not be able to understand new concepts and facts. A strong foundation will ensure that new knowledge is retained longer and stronger. Hence, it is important for educators to ensure that students' foundation knowledge is strong for them to understand important concepts. This is especially significant in the study of Newtonian (classical) mechanics. Newtonian mechanics is the central topic in introductory physics and force is one of the major concepts of all physics. A large number of students enrolled in introductory physics courses at both school and university level.

Since the 1980s, many of the physics education researchers have been focusing on students' conceptual understanding of physics and the misconceptions which barricade genuine conceptual physics learning process. Hence educators and researchers have developed numerous quantitative assessment instruments (Madsen, McKagan, & Sayre, 2017; Savinainen, 2004; Siang, 2011) to evaluate and improve physics learning and teaching. In the past three decades, about 50 Research-Based Assessment Instruments (RBAIs) have been developed for assessing the conceptual understanding and instruction effectiveness within the field of physics. Since Newtonian mechanics is the central theme of the first course in most physics sequences and it is needed for the rest of the sequence, it has the largest number of RBAIs. A few examples are the Mechanics Baseline Test (MBT), Force Concept Inventory (FCI), Force and Motion Conceptual Evaluation (FMCE), Inventory of Basic Conceptions in Mechanics (IBCM), Frictional Force Concept Inventory (FFCI), Force, Velocity and Acceleration Test (FVA) and Test of Understanding Graphs in Kinematics (TUG-K) (Madsen et al., 2017; Sharma & Sharma, 2007). Among these assessment instruments, FCI is the most internationally well-known and widely used standardized conceptual test of force and related kinematics.

Madsen et al. (2017) recommended the use of FCI to assess students' broad conceptual understanding of kinematics and Newtonian laws. Scores of the FCI test are more informative than scores from other forms of assessment given to students in introductory physics courses (Asma Said, 2015). Savinainen and Scott (2002) considered the Force Concept Inventory to be a significant instrument in physics education. They concluded that the FCI permits the instructor to analyze students' thinking in terms of specific misconceptions and in this way the instructor is in a better position to design and to implement new steps of instruction. A concept inventory is a kind of test by which students' conceptual understanding in a given area of physics can be measured. Hestenes and Halloun at the Arizona State University in 1985 produced a tool named the Mechanics Diagnostic Test (MDT) to identify students' misconceptions in mechanics. They developed the MDT for the expressed purpose of evaluating introductory physics teaching objectively. The test questions were initially selected to assess students' qualitative conceptions of force and motion. It is later improved to identify common misconceptions.

In 1992 the 34-item MDT was improved by Hestenes et al. to a new 29-item version called the FCI qualitative multiple-choice test (Hestenes, 1992). It was then revised and updated in 1995 by Halloun, Hake, Mosca, Hestenes, Wells, and Swackhamer to the current widely used 30-item version (Halloun et al., 2015; Mazur, 1999). Since then it has been used as one of the instruments to measure students' understanding of fundamental concepts in Newtonian mechanic. In addition, FCI was also used to assess teaching effectiveness in an introductory physics course (Hestenes & Halloun, 1995; Hestenes, Wells, & Swackhamer, 1992; Mazur, 1999; Von Korff et al., 2016).

According to the previous body of research, the difficulties of conceptual understanding are common among students. Surveys have found that most students have naive thoughts about the concepts of Newtonian Physics. The school and university students are commonly found to have understandings that are not scientifically accepted, also known as the alternative conception (Halloun & Hestenes, 1985; Van Heuvelen, 1991). Many researchers have studied and used the FCI and it has been translated into more than 30 languages (Halloun et al., 2015). In this study, the FCI 1995 version is translated into Pashto language and used to evaluate the conceptual understanding of a group of national high school and university students in Kabul, Afghanistan.

Physics Education in Afghanistan

The education system in Afghanistan is based on the American education system where it incorporates kindergarten to grade twelve (K-12) followed by the university level or higher education. There is no co-educational school system in Afghanistan. The schools have inadequate facilities and face serious challenges such as an inadequate number of professional teachers, lack of lab materials and technicians in most of the schools and laboratories. In addition, almost 50% of schools do not have usable buildings and 88% are without electricity (Education for All 2015 National Review Report: Afghanistan, 2015). Currently, only 43% of teachers have the required minimum qualification (grade 14 and above) to teach at all levels of general education. The present state of science education in Afghanistan, specifically in the basic education level, lags behind other countries in the world. In the current curriculum, from the 7^{th} to 12^{th} grade in Afghan schools, the students take only one physics course in each academic year covering topics from Mechanics to Modern Physics. The subject of introductory physics is introduced in the 7th grade, a very basic level to the current curriculum with introductory topics on measurement, force, work, electricity, and light. The Mechanics (Kinematics and Forces) topics are covered in the textbooks of the 11th grade. The topics which are studied at school level in mechanics include mechanical equilibrium, one-dimensional motion, two-dimensional motion, Newton’s laws of motion, work, mechanical energy and power, linear momentum and impulse, as well as fluid statics and dynamics (Afghanistan’s Ministry of Education, 2017).

University level education is run by the Ministry of Higher Education (MoHE) which include public (tuition-free) and private universities. At the university level, physics subjects are compulsory in some departments of faculties like Education, Sciences, Natural Sciences, Computer Science, Engineering, and Medicine. The physics curriculum implemented in Afghanistan's higher education institutions is not as updated as other countries. The curriculum consists of outdated materials and pedagogical skills which use the traditional teaching methods (Abdulbaqi, 2009; Samady, 2013). However, the Ministry of Higher Education of Afghanistan is working hard to improve and standardize the curriculum which could carry out what the market requires and could compete internationally (Baharustani, 2012). According to the curriculum of the Higher Education, a classical mechanics course is taken by undergraduate physics students in science faculties during the 3rd semester. Meanwhile, undergraduate physics students at the faculties of education and natural science take two classical mechanics courses (Mechanics I and II) during the 4th and 5th semesters.

Teaching and Learning of Physics in Afghanistan

In the last few years, the rapid build-up of the education sector in Afghanistan provides challenges both for ensuring and measuring the quality of the education system and conceptual learning. Strand in 2015 reported that by most standards, Afghanistan's education quality is very low, and the learning outcomes are generally poor. A few sample studies suggested that about less than 50% of the students are able to meet the minimum required learning outcome at their level of study. Furthermore, it was found that for technical training, most of the education is theoretical and of very little practical value (Strand, 2015). Additionally, teachers do not receive proper on-the-job support and almost 60% of teachers do not have the required qualifications, as well as many qualified teachers, teach subjects that they are not qualified for (Education for All 2015 National Review Report: Afghanistan, 2015).

In Afghanistan, Physics is known as a very difficult subject to teach and challenging for students of both schools and universities to conceptually learn it. Perhaps this is also true for students in many other countries. Anecdotal pieces of evidence in Afghanistan suggested that the common method of teaching physics, both in school and in university courses is often the traditional teaching instruction. This traditional method is teacher-centered in which the teacher plays the most important role in the classroom. In this method, the students are passive, and all they have to do is listen to the teacher and take notes. Teachers typically describe the content according to the textbooks and often give students notes to copy. The content is inflexible. There are very few students who discuss ideas in the class while the majority of them are silent. Therefore, students do not develop good understandings of physics concepts. For many students, learning physics is the only memorization instead of conceptual understanding. Limited trained teachers, lecturers and laboratory staffs in schools and universities of Afghanistan have impeded the development of physics teaching and learning in the country. Almost four decades of war had a damaging effect on education in general including physics education in Afghanistan. Therefore, one of the most important goals of leaders in higher education, as stated in the National Higher Education Strategic Plan, is to develop better teaching and learning environments (Afghanistan Ministry of Higher Education, 2017).

In the last decade, the government of Afghanistan undertook considerable effort to increase the number of university lecturers with masters and doctoral degrees as well as increase the enrollment of female students in many areas of studies including physics in Afghanistan universities. Partnerships with a number of American, European and some Asian universities have contributed in enhancing the quality of higher education, through training, research, application of new technologies, development of curriculum and teaching materials (Babury & Hayward, 2014; Samady, 2013). At the same time, efforts are also done at the school level wherein 2013 new textbooks for schools from grade 1 to 12 were launched. During the period of 1996-2001, education was only made available to boys.

Prior to 2002, less than one million almost all boys attended government schools. However, in 2016 more than nine million children were enrolled in schools which included girls, who were almost completely prevented from attending school before 2001. Currently, about 35% of school students are girls. The number of high school graduates increased from about 10,000 in 2001 to more than 300,000 in 2017 (Afghanistan's Ministry of Education, 2017). The Ministry of Education has expanded the Teacher Training Colleges (TTCs) and centers to support teachers at central, provincial and district levels in order to improve the level of knowledge of new and current teachers. Teacher training colleges offer a range of training options aimed at new and practicing pre-service and in-service teachers in order to increase the qualification level of teachers already in the field. The National Strategic Plan for Education in Afghanistan planned that by 2020, new curriculum, textbooks and teacher guides based on active learning approaches will be running in schools. Female teachers will be increased by 50%, increasing enrolment rates for primary schools for girls and boys of a least 75% and 60% respectively (Azam, Fauzee, & Daud, 2014; Education for All 2015 National Review Report: Afghanistan, 2015).

METHODS

According to the literature review, there is no study which has investigated the level of conceptual understanding of introductory physics among the students of schools and universities in Afghanistan. Furthermore, even though the FCI has been translated into 32 versions of different languages, it has not been translated into Pashto which is an official and the largest ethnic group language in Afghanistan or any other languages in Afghanistan. Therefore, there is a need to perform this study and choose a suitable instrument to evaluate the level of conceptual understanding of Newtonian mechanics of Afghan school and university students. The FCI test was administered to 216 male students from 6 classes in two high schools as well as to 50 males and 40 female university physics students from 3 classes in two universities. The classes and students were randomly selected, and the test was given to them in April 2017. The respondents answered the FCI test in 50 minutes. Descriptive and inferential statistical analysis methods were used to determine the students' level of conceptual understanding in Newtonian mechanics.

First, the 1995 FCI English version was selected as an assessment instrument in this study. Secondly, it was translated to Pashto language and then validated by faculty members whose major was physics and had competency in both languages English and Pashto, in order to preserve the questions in its original nature. The Pashto words chosen in this translation are commonly used by students in their daily conversation. Thirdly, permission was requested to carry out the study from the Ministry of Education for school students and from the Ministry of Higher Education for university students in Afghanistan. After permissions were granted from the Ministries the FCI Pashto version was administered to the respondents in the respective schools and universities. Finally, the answers were analyzed using the Statistical Package for Social Science (SPSS) and Microsoft Excel.

The SPSS version 24 and Microsoft Excel were used to analyze the difference in FCI scores of high school and university students as well as the scores of students from Kabul University and Kabul Education University. The collected data were analyzed using descriptive and inferential statistical analysis methods. The levels of students' conceptual understanding were also analyzed based on the six conceptual dimensions of the FCI.

RESULTS

The results in this investigation showed that the overall average score of school and university students was 22%, where the mean score of school students was 20% while that of university students was 26%. The mean FCI score of university students is 6% higher than that of the school students. A non-parametric two-independent test shows that the 6% difference in the FCI scores is statistically significant at 0.05 level. Meanwhile, the mean FCI score obtained by Kabul University and Kabul Education University students was 27% and 24% respectively. The results of the independent samples t-test indicated that there is no significant difference between the mean FCI scores of students from the two universities at the 0.05 level. This study also shows the distribution of FCI scores based on the gender of university physics student respondents. In Kabul University, male students obtained slightly higher scores (29%) in the FCI test compared to the female students (26%), while there is no great difference between female and male students mean FCI scores in Kabul Education University. In Kabul Education University male and female students obtained approximately the same scores (25%) and (24%), respectively. A parametric independent samples t-test showed that there is no statistically significant difference between the test scores of female and male students at the university level.

Hestenes et al. identified six conceptual dimensions of Newtonian mechanics measured by the FCI test and classified each test item into one or more than one of these conceptual dimensions. The percentage of correct answers of the respondents according to the dimensions in the FCI are presented in **Table 1**.

It shows that students had the highest score of 26% on the concept of Newton's First Law of Motion. This is followed by 24% on the conceptual dimension of Kinds of Force, 23% on both Newton's Second Law of Motion and the concept of Superposition Principle. Finally, the lowest scores are obtained in both conceptual dimensions of the Newton's Third Law of Motion and kinematics (19%). These results illustrated that the students hold serious misconceptions about kinematics and the Newton's Third Law of Motion concepts. This is followed by the concepts of Newton's Second Law of Motion and Superposition principle, concepts of Kinds of force, and the concepts of Newton' First Law of Motion.

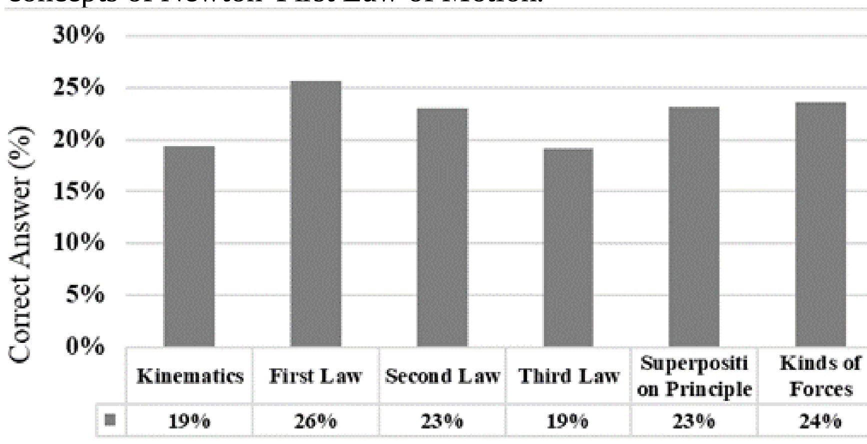

Figure 1. *The Percentage of Correct Answers in The Six Conceptual Dimensions of FCI*

Hestenes and Halloun classified 3 levels in the students' conceptual understanding of Newtonian mechanics based on their mean FCI scores. First, students who obtained the mean FCI score of less than the conceptual entry threshold of 60% have difficulty in understanding Newtonian force concepts. Secondly, students who achieved scores between 60% and 85% have fairly coherent Newtonian mechanics concepts. Finally, those who obtained the mean scores of above 85% on the FCI are confirmed Newtonian thinkers (Hestenes & Halloun, 1995). This information is summarized in **Table 1**.

Table 1. *Level of Conceptual Understanding*

Students' Scores Range (%)	Level of Conceptual Understanding	Characteristics of the Level of Conceptual Understanding
$0 \leq x < 60$	Weak and have difficulty	Low understanding in Newtonian force concepts
$60 \leq x < 85$	Newtonian Entry Threshold	Beginning to think like Newtonian thinkers
$85 \leq x \leq 100$	Newtonian Mastery Threshold	Threshold as complete Newtonian thinkers

According to the above classification, none of the respondents either from schools or universities reached the 60% Newtonian entry threshold level of conceptual understanding of Newtonian Mechanics.

DISCUSSION

In general, the purpose of this research was to determine the level of conceptual understanding in Newtonian mechanics among school and university students in Afghanistan. The results of this research illustrated that students, especially school students had many significant misconceptions in all parts of Newtonian concepts. These results confirmed most of the results of prior studies which reported that, in general, students are still having difficulties in qualitative and conceptual understanding of physics concepts both in schools and universities (Abdal Razzaq, 2014; Bani-Salameh, 2017; Bayraktar, 2009; Fadaei & Mora, 2015; Nur & Shahrul, 2014; Sharma & Sharma, 2007). School and university students' misconceptions about Newtonian concepts have also been investigated in different countries and cultures by using the FCI as the assessment instrument (Bayraktar, 2009; Fadaei & Mora, 2015; Sharma & Sharma, 2007; Von Korff et al., 2016).

Non-parametric tests, Kolmogorov - Smirnov test of two independent samples and Mann-Whitney U two independent samples test, were used instead of the t-test because the data from the sample of school students were not normally distributed. Even though the results showed that university students are significantly better than the school students in almost all the six conceptual dimensions, with the exception of the kinematics dimension where the scores were about the same, most of the test items were very difficult for both school and university students. Similar FCI results where university students performed significantly better than the school students were also reported by Planinsic et al. in a study of Croatian students' conceptual understanding of Newtonian mechanics. In this study, the mean FCI score of 1676 Croatian school students was 28% while the mean FCI score of 141 university students taking Introductory Physics course in university was 65% (Planinic, Ivanjek, & Susac, 2010). However, Usawinchai who investigated the FCI performance of Thai students reported that the range of mean FCI scores of grade 12 students is 28%-39% while the mean FCI score of university students was 34%. Hence indicating no significant difference between the mean scores of school and university students in Thailand (Usawinchai, 2003). Similar results were reported by Sharma and Sharma where there is no significant difference in most answers of students at a school, university, graduate and postgraduate levels in FCI tests (Sharma & Sharma, 2007).

One of the most important findings in this study shows that there is no significant difference in the conceptual understanding of Newtonian mechanics between the male and female university students. However, the effects of gender on the FCI scores for high school students cannot be studied due to restrictions from the Afghanistan Ministry of Education that a male researcher is not permitted to administer the test to female students.

Some previous physics education studies in students' conceptual understanding and misconceptions about Newtonian physics have given similar results with regard to gender differences. Kiong and Sulaiman found that male and female students had the same level of conceptual understanding of Newtonian concepts with no significant gender difference. The researchers found the average FCI scores for 42 female students was 25% and that of 26 male students was 24%. In this study female and male students hold approximately similar misconceptions about Newtonian force concepts in all conceptual dimensions (Kiong & Sulaiman, 2010). In another study by Abdal-Razzaq (Abdal Razzaq, 2014) found that the average FCI scores for 33 females and 239 male students were 28% and 26%, respectively with no significant gender difference. In another recent study at a community college in California, Said (A Said, 2015) reported that there is no gender gap in the average FCI scores between the female and male students in university introductory physics courses.

In his study, male and female students held approximately the same level of conceptual understanding and types of misconceptions in force and motion concepts. However, there are other studies using FCI which found a statistically significant difference between the scores of female and male respondents. In other words, numerous studies have shown that gender has an influence on physics achievement. Docktor and Heller reported that there is a significant gender gap in pre-test FCI scores. After using a nonparametric test, they observed that male students' average FCI score is a little higher than that of female students (Docktor & Heller, 2008). Kost et al. found that male students' average score in FCI is significantly higher than that of female students (Kost, Singh, Vaughan, Trussell, & Bankole, 2008). In another study in Finland by Ahtee et al., (2001) reported that the average FCI scores for female and male university students were 51% and 61%, respectively where the average score of male students is 10% higher than that of female students which are statistically significant.

In a research carried out in Tehran, Iran by Fadaei and Mora (2015) on a sample of 20 female school students, the average Persian version FCI test score of these students after traditional teaching was only 21%. This average score is very close to that of Afghan school students average Pashto version FCI scores of 20%. Meanwhile the average scores for a Filipino version FCI from a sample of 459 grade 10 Filipino students from 10 public schools was only 15% (Tadeo & Roleda, 2013). This result from the Filipino students is lower than the average FCI scores of the Afghan students.

There exist various factors that may contribute to the low FCI scores of Afghan school students in this study. First, there are insufficient qualified physics teachers in Afghanistan where according to the Ministry of Education statistics, only 10% of the teachers in schools are graduates from universities with bachelor's degree from which only about 1% are graduates from Physics. The rest of the teachers are having the following qualification: 43% graduated from grade-14 (Teacher Training Program), 38% graduated from just grade-12 (High School), and 9% have not finished schools (Student Teacher) (Afghanistan's Ministry of Education, 2017). Next, poor laboratory and library facilities deprived the students of hands-on experience in learning physics.

Finally, the poor results may be attributed to the traditional physics teaching approach in which the teachers described and delivered the content according to the textbooks with an emphasis on mathematical equations and quantitative problem solving while giving less importance to conceptual understanding. As for the FCI scores of university students, even though they were significantly higher than those of school students, they were still in the category of low scores and did not reach the Newtonian entry threshold scores of Newtonian thinkers. These low scores of university students may be attributed to similar reasons as stated for the situation in Afghanistan schools.

There is a small number of qualified lecturers at the university: less than 5% with Ph.D., about 30% with Masters and about 65% with only Bachelor degree (Babury & Hayward, 2014; Samady, 2013). Inadequate laboratory and trained staff and library facilities (Samady, 2013). as well as traditional physics teaching approach may have contributed to this low performance in the FCI at the university level. The results from many physics education researches showed that traditional teaching approaches did not greatly promote students conceptual understanding at school and university level. At the same time, students' misconceptions were resistant to change by traditional teaching approaches. A study by Abd Rahman et al. concluded that traditional instruction had little effect on changing the students' beliefs (Abd Rahman et al., 2007). In another study by Abdal Razzaq it is stated that the traditional method of teaching

Newtonian Mechanics had no effect on the Post FCI test results (Abdal Razzaq, 2014). Hake, Mazur, Kim and Pak, Bayraktar, and Von Korff et al. found that traditional teaching of classical mechanics classes did not significantly promote conceptual understanding in Newtonian physics classes (Hake, 1998; Mazur, 1999; Von Korff et al., 2016). Likewise, the FCI results between 1995 and 2014 for over 30, 000 students have shown that traditional teaching did not help students learning the fundamental concepts in Introductory Physics (Madsen et al., 2017).

Strayhorn stated that school environments affected student learning outcomes and teachers play an important role in the academic success or failure of students (Strayhorn, 2010). Moreover, in the study of introductory physics, laboratory exercises are very important. The laboratory work as an instructional approach helps the school and university students master fundamental physics concepts (American Association of Physics Teachers, 1998; Royuk, 2002). The science laboratory can be excellent surroundings for conceptual understanding (American Association of Physics Teachers, 1998). These FCI results from Afghanistan schools and universities were not surprising considering that almost four decades of war had badly affected the human resources, laboratories, and libraries in schools and universities in this country. The results of this study could be used as important findings for future improvement of physics teaching and learning in Afghanistan at the school and university levels.

CONCLUSIONS

In general, the respondents in this study have a poor level of conceptual understanding and possessed many misconceptions in Newtonian mechanics as reflected by their low marks in the six conceptual dimensions of the FCI. The Pashto version of the FCI is an important assessment instrument to gauge the students understanding of Newtonian Mechanics and the effectiveness of physics teaching in Afghanistan. This instrument can be used to investigate the performance of students in other Pashto speaking regions. This is an important first step towards improving physics teaching and learning as well Physics Education Research (PER) in a country ravaged by years of war. The results will help educators and physics curriculum planners to revise the teaching approach and contents of school textbooks in this subject. It is hoped that the results of this investigation will be useful for the Ministry of Education and the Ministry of Higher Education in Afghanistan to further develop physics teaching and learning in the country with special emphasis on conceptual understanding.

RECOMMENDATIONS AND FUTURE WORK

The poor Afghan student understanding of Newtonian mechanics as shown in this study requires both ministries of Education and Higher Education to focus more on the development of teachers training, facilities, and curriculum that can improve the learning of physics in Afghanistan so that it is at par with other developed countries. Interactive engagement or active learning teaching techniques could be adopted to improve students conceptual learning as reported in a study of 50 thousand students from 1995 to 2014 in the USA by Von Korff et al. (Von Korff et al., 2016).

It is recommended that further research should be carried out to investigate the reasons behind the poor results and practical approaches to improving them. The relationship between students' conceptual understanding of introductory physics and their quantitative problem-solving abilities in introductory physics could also be studied. The study should also be extended to other regions throughout Afghanistan including the Dari speaking students by employing the Dari version of the FCI. This study could also be carried out to a larger group of male and female students from different government and private schools. This will enable comparison to be made between the performance of public and private school students as well as female and male students at school level.

Other RBAIs such as the Force and Motion Conceptual Evaluation (FMCE) can also be used to gather more data on student understanding of Newtonian mechanics. The research area could also be extended to include other assessment instruments beyond Newtonian physics such as Conceptual Survey of Electricity and Magnetism (CSEM), Mechanical Wave Conceptual Survey (MWCS), Quantum Mechanics Concept Inventory (QMCI), and Relativity Concept Inventory (RCI).

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