Conceptual coherence and dominant misconceptions in the concept of force among higher education students: The administration of Force Concept Inventory

Abstract

The paper reported here is a part of a larger 8000 student survey to determine the common misconceptions regarding Newtonian mechanics among Bhutanese students. The force concept inventory (FCI) was used as a diagnostic instrument to probe students' misconceptions regarding the concept of force in physics. The objective of the research was to determine the extent to which student scores demonstrated conceptual coherence, Newtonian thinking, and identify dominant misconceptions. Data was collected from university students majoring in physics (N = 40), year I and year IV pre-service teachers (N=155), by administering the questionnaire face-to-face. Data was analysed using descriptive statistics. Results suggests that students are not able to consistently apply Newtonian mechanics, and none have reached the Newtonian thinking threshold. Dominant misconceptions were identified in relation to kinematics, Newton's first, second, and third laws of motion, superimposition principle, and kinds of force. Implications for practice is discussed.

Keywords: Newtonian mechanics, dominant misconceptions, Newtonian threshold, conceptual coherence,

Introduction

David Ausubel (1968) in his groundbreaking book of educational psychology wrote, "if I had to reduce all of educational psychology into one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (p. vi). The necessity to identify, delineate, and explore student conceptions about every scientific phenomenon has been one of the most prolific programs of research in science education (Anderson, 2007). This area of research has been prioritized after recognizing that teaching for conceptual change involves students articulating and examining their conceptions about various phenomena connected to the scientific topic. Conceptions which are incompatible with established scientific theory are labelled as "misconceptions' and are quickly dismissed by scientists (Halloun & Hestenes, 1985). Smith et al. (1993) refer to learner misconceptions as "faulty extensions of productive knowledge" (p. 152) and the term is synonymously used with a wide range of terms, including but not limited to, alternative frameworks, preconceptions, prior knowledge, student ideas and in the field of science education research (Larkin, 2012; Vosniadou & Skopeliti, 2019). In this study, misconceptions besides its regular meaning shall also be used to describe the other terms mentioned above.

An important question emerges; do misconceptions assist or hinder learning? There remains a lack of consensus in the field of science education whether to consider learners' misconceptions as resources or obstacles to teaching for conceptual change (Larkin, 2012). Two prominent bodies on the forefront of science education research, American Association for the Advancement of Science (AAAS) and National Research Council (NRC) remains divided on the role misconceptions play in a constructivist's classroom:

> Clearly, alternative conceptions can interfere with learning, suggesting that instruction must be carefully designed to address preexisting ideas. (AAAS, 2011, p 384)
>
> Some of the children's early intuitions about the world can be used as a foundation to build remarkable understanding, even in the earliest grades. Indeed, both building on and refining prior conceptions (which can include misconceptions) is important in teaching science at any grade level (NRC, 2012, p. 30)

Despite the incongruence, it is imperative that misconceptions be identified and delineated in greater detail first, germane to the context, to design coursework or teaching learning materials to address them. In this paper, attempts were made to identify and describe the extent of alternative conceptions with respect to the concept of force.

There is a growing body of research suggesting that traditional model of teaching does not assist students in developing conceptual understanding of Newtonian mechanics (Hake, 1998; Hake 2002; Hestenes et al., 1992; Malone, 2008). According to Hewson (1992) traditional model of teaching reinforces the accepted conceptions, by compelling students to accept what is already known about, both the processes involved and the result of an enquiry. This view of teaching does not offer students with the flexibility to challenge the status quo and indulge creatively, reflectively, and innovatively in developing strategies to test and verify alternative conceptions. On the contrary constructivist's approaches to teaching, such as interactive-engagement (Hake, 1998), modelling instruction (Hestenes et al., 1992), Interactive conceptual instruction (Savinainen & Scott, 2002) have found a significant improvement in students' cognition of Newtonian mechanics through a pre-post test data. Besides these approaches, conceptual change model to classroom instructions (Posner et al., 1982) and its variations (Potvin et al., 2020) have been extensively used to address students' misconceptions in science.

Purpose of the study:

The purpose of this quantitative study is to;

(1) Conduct a baseline study involving students from different sectors of education in Bhutan,

(2) Identify predominant preconceptions regarding the concept of force among Bhutanese university students and pre-service science teachers,

(3) Compare the contextual coherence among different groups of participants.

Research questions

This quantitative research is guided by the following questions:

(1) What proportion of students demonstrate contextual coherence on the concept of mechanics?

(2) What are the predominant misconceptions regarding mechanics among students in Bhutan?

Theoretical Framework

In this research, conceptual coherence is used as the unit of analysis. Conceptual coherence of students understanding can be broadly classified into the following three aspects: representational, contextual, and conceptual framework coherence (figure 1). Representational coherence refers to students' ability to use multiple representations of the same situation and succinctly move between them (Savinainen & Viiri, 2008). A physical concept can be represented in various ways such as verbal (written and oral), diagrammatic (vectors, motion maps, path diagram), and graphical (graphs, eg. velocity time graph). According to Van Heuvelen (1991), these representations are efficient tools which assist in analysing physical situation. Contextual coherence refers to students' ability to apply a concept (eg. gravity) or a physical law (in this case Newton's Laws of motion) in a variety of familiar and novel context. The context here refers to the circumstantial feature in which the task is posed (Savinainen & Viiri, 2008). Contextual coherence must be evaluated in conjunction with one or other forms of representations depicting the students' understanding of the given situation. Conceptual framework coherence addresses the relationships between concepts and overlaps other aspects to some extent. To apply a concept in a variety of contexts, the learner must relate (integrate) a concept to other concepts. They also need to differentiate a concept from related concepts (McDermott, 1993). Conceptual framework coherence is about how relevant concepts fit together (Savinainen & Viiri, 2008). For example, to solve a problem related to acceleration, sometimes, a student should also apply the concept of velocity. But conceptual framework coherence would demand that the student should also be able to differentiate between the two concepts.

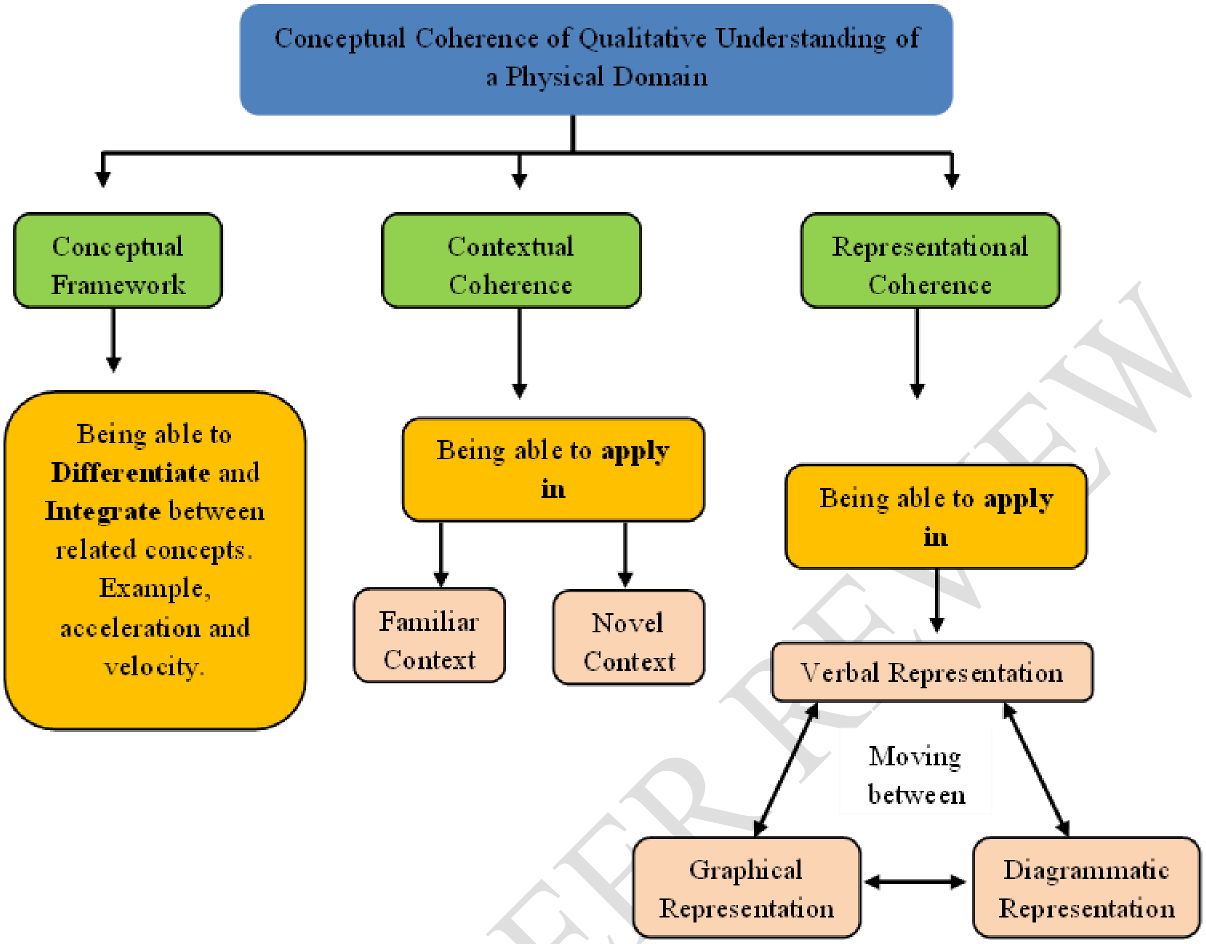

Figure 1: Aspects of Conceptual coherence of qualitative knowledge in Physics. Adapted from Savinainen and Viiri (2008).

Science Education Research

A growing number of empirical studies (Education Sector Review Commission (ESRC), 2008; Johnson et al., 2008; iDiscoverie Education (iDE) & Royal Education Council (REC), 2009; Sieber, 2009; Southeast Asia human Development Unit, 2009) suggest teachers are failing to actively engage students in the classroom, in a manner that is congruent with construction of knowledge (Vygotsky, 1978). The prevailing transmission reception model of teaching (Johnson, et. al, 2008; iDE & REC, 2009), among other factors such as volume of content within prescribed syllabi (Jonhson, et al., 2008; iDE & REC, 2009), examination as the only form of assessment to examine students' performance (ESRC, 2008; Powdel, 2005), students graduating to higher classes without compatible skills and knowledge to comprehend and perform tasks related to instruction, incoherent flow of concepts across grades, and teacher incompetence (ESRC, 2008; Johnson, et al. 2008; iDE & REC, 2009; Southeast Asia Human Development Unit, 2009) are criticized for student's underperformance. The status is reported to be particularly grim for Physics 12 (Johnson, et al. 2008). Suggestions from almost all the researchers infer that teachers are not competent enough, that they lack both subject matter expertise and pedagogical content knowledge to translate prescribed content to appropriate learning tasks.

Earlier research on mechanics

The central concept of Newtonian mechanics is force. Hestenes and colleagues (Halloun & Hestenes, 1985; Hestenes, Wells &Swackhamer, 1992) over a span of almost a decade conducted numerous quantitative studies to list students' preconceptions about force and the effects of force. Halloun and Hestenes (1985) recognize that students are not able to dismiss preconceptions that are not compatible with modern scientific theory as misconceptions because they are grounded in long personal experiences. They termed such preconceptions as "common sense" (CS) beliefs or preconceptions or misconceptions. Similarly, Hestenes et al., (1992) assert that every student have a "well-established system of CS beliefs about how the physical world works" (p. 1) derived from years of personal experience even before their formal physics instruction starts.

Physics education research has established that these beliefs play a dominant role in introductory physics. Instruction that does not take them into account is almost totally ineffective, at least for the majority of students. Specifically, it has been established that (1) commonsense beliefs about motion and force are incompatible with Newtonian concepts in most respects, (2) conventional physics instruction produces little change in these beliefs, and (3) this result is independent of the instructor and the mode of instruction (Halloun & Hestenes, 1985). The implications could not be more serious. Since the students have evidently not learned the most basic Newtonian concepts, they must have failed to comprehend most of the material in the course. They have been forced to cope with the subject by rote memorization of isolated fragments and by carrying out meaningless tasks. Thus, from a conceptual coherence framework, it can be safely presumed that common sense beliefs or misconceptions regarding the concept of force hinder the holistic conceptualization of the topics taught in the class.

The instrument

The Force Concept Inventory (FCI, Hestenes et al., 1992) is the most widely used assessment instrument of student understanding of mechanics (Henderson, 2002; Martin-Blas et al., 2010; McDermott & Redish, 1999; Planinic et al., 2010; Thorton et al., 2009). This study used the 1995 version of FCI. This 30-item multiple choice test requires a forced choice between Newtonian concepts and commonsense alternatives, and simultaneously investigates students' conceptual understanding of Newtonian force concept with minimal use of mathematics. According to Martin-Blas et al. (2010), the questions are qualitative rather than focusing on problem solving. As a rule, errors on the inventory are more informative than correct choices (Hestenes, Wells, &Swackhamer, 1992). The commonsense alternatives to the Newtonian concepts are commonly labelled as misconceptions. They should nevertheless be accorded the same respect we give to scientific concepts. Accordingly, these commonsense beliefs should be regarded as reasonable hypotheses grounded in everyday experience. They happen to be false, but that is not always so easy to prove, especially if they are dismissed without a hearing as ill conventional instruction. The Inventory, therefore, is not a test of intelligence; it is a probe of belief systems (Hestenes et al., 1992).

The FCI is not just another physics test. It assesses a student’s overall grasp of the Newtonian concept of force. Without this concept the rest of mechanics is useless, if not meaningless. It should therefore be disturbing rather than comforting that students with only moderate scores on the Inventory may score well on conventional tests and get good grades in physics. The FCI can be used for both instructional and research purposes. The applications fall in three main categories. However, in this study it is used only as a diagnostic tool. As a diagnostic tool, the Inventory can be used to identify and classify misconceptions. It is especially valuable for teachers, to raise their awareness of misconceptions among their own students. Each FCI question requires the student to choose a Newtonian answer from four alternative non-Newtonian responses (Hestenes & Halloun, 1995). The distracters have been carefully constructed consequent thorough interviews about non-Newtonian answers to each question. Planinic et al, (2010) confidently assert that FCI now has become a standardized instrument for measurement of students’ conceptual understanding of mechanics. Hestenes and Halloun (1995) suggest that an FCI score of 60% as the entry threshold to Newtonian physics, meaning students have barely begun to use Newtonian concepts coherently in their reasoning. Below this threshold student understanding of Newtonian concept is insufficient for effective problem solving and such students have difficulties following physics course at university level (Hestenes & Halloun, 1995).

The conceptual domains of FCI

The FCI addresses six conceptual dimensions within the domain of force and related kinematics. Table I classifies the Newtonian concepts probed by the inventory, along with the inventory items in which they appear. The items are the correct Newtonian answers to the inventory questions. According to Hestenes, Wells, and Swackhamer (1992), all the six dimensions are essential to the Newtonian concept since they together portray the complete concept.

Table I.
Newtonian Concepts in the Revised Force Concept Inventory (1995).

	Inventory Item, correct response
0. Kinematics	
Velocity discriminated from position	19E
Acceleration discriminated from velocity	20D
Constant acceleration entails	
parabolic orbit	12B, 14D, (21E)
Changing speed	(22B)
Vector addition of velocities	9E
1. First Law	
with no force	6B, 7B, 8B, (11D)
Velocity direction constant	23B
speed constant	10A, 24A
with cancelling forces	17B, 25C

2. Second Law	
Impulsive force	(8B), (9E)
Constant force implies constant acceleration	21E, 22B, 26E
3. Third Law	
for impulsive forces	4E, 28E
for continuous forces	15A, 16A
4. Superposition Principle	
Vector sum	(8B), (9E)
Cancelling forces	(11D), (17B), (25C)
5. Kinds of force	
5S. Solid contact	
passive	11D, 29B
impulsive	5B, 18B
friction opposes motion	27C
5F. Fluid contact	
air resistance	30C
buoyant (air pressure)	none
5G. Gravitation	3C, (5B), (11D), (12B), 13D, (17B), (18B), (29B), (30C)
acceleration independent of weight	1C, 2A
parabolic trajectory	12B, 14D

Adapted from Hestenes et al., 1992.

It is evident from Table 1 that some of the questions overlap into two conceptual dimensions. This posits a problem in analyzing data and identifying predominant misconceptions. Savinanen and Viiri (2008) carefully reconsidered the inventory questions which were originally classified into two conceptual dimensions by Hestenes et al., (1992). They presented a similar yet different classification of FCI questions, in which a question represented only one dimension. The reasons and justification of the re-classification can be seen elsewhere (see Savinanen & Viiri, 2008) for details. Table II presents the classification presented by Savinanen & Viiri (2008). For this study, this classification system and corresponding data analysis was used. However, inventory questions 9, superimposition principle, and 21, diagrammatic Newton’s Second Law of motion, are excluded from the classification since one question in those is not enough to allow a comprehensive evaluation of misconceptions (Savinainen & Viiri, 2008).

Table II

Classification of FCI questions in terms of representation and the dimensions of force concept.

Dimensions of force	Kinematics	Newton’s First Law		Newton’s Second La	Newton’s Third Law	Kinds of Force	
						Gravitation	Contact
Representation	Diagram	Verbal	Diagram	Verbal	Verbal	Verbal	Verbal

FCI Question	12, 14, 19, 20	10, 17 24, 25	6, 7, 8, 23	22, 26, 27	4, 15, 16, 28	1, 2, 3, 13	5, 11, 18, 29, 30

Adapted from “The force concept inventory as a measure of students conceptual coherence” by A. Savinanen and J. Viiri, 2008, International Journal of Science and Mathematics Education.

Data Collection and method of analysis

Three groups of Bhutanese students in higher education participated in this study. A cohort of university students majoring in Physics (n = 40), and two cohorts (year I and year IV) of pre-service teachers specializing to teach physics (n = 155) contributed data. The instrument was administered face-to-face by a team of enumerators, who were trained.

Contextual coherence

The FCI results for the six dimensions and representation categories (Table II) were classified into three levels of achievement in contextual coherence as proposed by Savinainen and Viiri (2008). They were as follows;

I. ‘no contextual coherence’: zero or one question answered correctly.
II. ‘partial contextual coherence’: at least two correct answers and at least one incorrect answer.
III. ‘contextual coherence’: all questions answered correctly.

According to Savinainen and Viiri (2008), this classification resembles Thorton’s (1995) three-fold classification, Student view, Transition State and the Physicist view, to describe the process by which students’ views are transformed during instruction.

Newtonian thresholds

Two benchmarks have been set and defined by the authors of FCI (Halloun & Hestenes, 1995; Hestenes et al., 1992). A FCI score of 60% is considered as a threshold for the development of Newtonian thinking. Similarly, Hestenes and Halloun (1995) describe a score of 85% and above as that of a Newtonian thinker. The thresholds can be interpreted as follows; if a student scores 60% in the FCI, she has barely begun using the concepts of Newtonian mechanics coherently. On the contrary, if she scores 85% and above, she uses the concepts coherently.

Dominant misconceptions

To identify the dominant misconceptions for a particular dimension of FCI, a cut off score of 50% was used. This is similar to the cut off percentage used by Martin-Blas et al., (2010). An incorrect answer was considered as being dominant, if it represented 50% of incorrect answer. In addition to the above condition, if all the groups of participants have selected the same incorrect inventory item, then is shall also be considered as a dominant misconception, albeit the 50% rule.

Results

A. *Average FCI Score*

To determine how the participants performed in FCI, individual questionnaire was evaluated and graded in percentages. All computations in this section will be in percentages.

Table III provides a summary of the average test scores, which was computed using descriptive statistics at a 95% confidence interval. Year I pre-service teachers scored the highest of 34.62% with a standard deviation of 6.9, while year IV pre-service teachers scores were 43.3%. University students majoring in physics scored 37% in FCI.

Table III
Summary of average FCI

Class	**FCI % (S. Dev)**	**Max**	**Min**	**N**
Pre-service teachers				
Year I	20.7 (6.9)	34.6	7.7	69
Year IV	18.9 (7.5)	43.3	3.3	86
University students				
	18.8 (6.4)	36.7	3.3	40

Mean score shown above are in percentage of correct responses. It is interesting to note that the mean score for Year I pre-service teachers was higher than that of Year IV students. A part of the reason may be because mechanics was being taught at the time of the inventory administration.

B. *The search for contextual coherence*

As described in the method of analysis section, to determine the conceptual coherence, individual students' responses were grouped as per the six conceptual dimensions and the total number of correct answers were noted in percentages. The benchmarks used to derive a conclusion about contextual coherence were similar to that of Savinainen and Viiri (2008). The results obtained is provided in table IV. To determine contextual coherence, all responses provided by the participant had to be correct (represented by the highest number value in the response column). Kinematics dimension in the FCI consists of four questions. However, the possibility of scoring is five, including no correct answer in the dimension or zero. In table IV, 11 university students of the total 40 (forty), answered one question correctly in the kinematics dimension. More importantly and unfortunately worrisome, is that majority (almost one-half) of the students in all the groups did not answer even a question correctly. In Kinematics and kinds of force (contact), none among the total population had achieved conceptual coherence.

Table IV: university students of the total 40 (forty), answered one question correctly in the kinematics dimension.

Dimension	Correct response	University (% correct)	Year IV (% correct)	Year I (% Correct)
Kinematics	1	11(27.5)	35 (40.7)	32 (46.4)
	2	3 (7.5)	11 (12.8)	8 (11.6)
	3	1 (2.5)	0	0

	4	0 (0)	0	0
1st Law (Diagram)	0	25 (62.5)	40 (46.5)	29 (42)
	1	22 (55)	37 (43)	30 (43.5)
	2	3 (7.5)	8 (9.3)	8 (11.6)
	3	1 (2.5)	0	0
	4	0 (0)	0	0
1st Law (Verbal)	0	14 (35)	41 (47.7)	31 (44.9)
	1	23 (57.5)	35 (40.7)	32 (46.4)
	2	11 (27.5)	27 (31.4)	19 (21.5)
	3	2 (5)	7 (8.1)	3(4.3)
	4	0	1** (1.2)	0
2nd Law	0	4 (10)	16 (18.6)	15 (21.7)
	1	21 (52.5)	27 (31.4)	23 (33.3)
	2	1 (2.5)	5 (5.8)	3 (4.3)
	3	1 (2.5)	0	0
3rd Law	0	17 (42.5)	54 (62.8)	43 (62.3)
	1	13 (32.5)	28 (32.56)	22 (31.9)
	2	4 (10)	16(18.6)	6 (8.7)
	3	8 (20)	9 (10.47)	4 (5.8)
	4	2^^ (5)	0	0
Gravitation	0	13 (32.5)	33 (38.37)	37 (53.6)
	1	8 (20)	23 (26.7)	28 (40.6)
	2	2 (5)	11 (12.8)	2(2.9)
	3	0	1 (1.2)	1 (1.4)
	4	0	0	0
Contact	0	30 (75)	51 (59.4)	38 (55.1)
	1	10 (25)	46 (53.5)	31 (44.93)
	2	6 (15)	11 (12.8)	12 (17.39)
	3	0	2 (2.3)	1 (1.45)

4	0	0	1 (1.45)
5	0	0	0
0	24 (60)	27 (31.4)	24 (34.78)

Frequency of the correct response against each dimension. * Constituted 0.33% of the sample. ** came to 1.16% of the sample. *** was 0.11%, ^ was 0.99%, ^^^was 5 %, $ was 1.99%, and $$ was 0.11 %. The percentages were calculated within the sample in the population and is not representative of the whole research population.

Results in table V, suggests that in kinematics, none of the participants in all the groups have attained contextual coherence. However, more alarming, the data suggests, is that university students who already have completed a course/module (six months of classroom instruction) still has not achieved contextual coherence. 90 % of university students, 87.2% of Year IV, and 88.4% of Year I pre-service teachers did not exhibit contextual coherence in kinematics.

In the diagrammatic representation of Newton's First Law of motion, tertiary students appear to lack contextual coherence. According to the benchmarks adopted, 95 % of university students, 90.7 % of Year IV, and 88.4 % of Year I pre-service teachers did not exhibit contextual coherence.

Participants, across all the groups, appear to have fared better in Newton's First Law (verbal representation) dimension than all the other dimensions. Although the number of students who exhibited contextual coherence, were a mere 1 from Year IV pre-service teachers (1.2 %), there was a significant increase in the percentage of students who exhibited partial contextual coherence. In terms of performance on individual dimension, Newton's first law (verbal) appears to be the least problematic area compared to the others.

Newton's second law of motion appears to be the most mis-understood concept among the six conceptual dimensions. According to the benchmarks set, 95 % of university students, 94.2 % of Year IV, and 95.7 % of Year I pre-service teachers have no contextual coherence against 7.5%, 2.5 %, 5.8 %, and 4.3% of students exhibiting partial coherence respectively. 2.5 % of university students (1 of 40) exhibited contextual coherence in this dimension.

In Newton's third law of motion, 5% (2 students) university students exhibited contextual coherence. However, no contextual coherence was exhibited ranging from 65% of university students to 85% (Year I pre-service teachers).

Table V

Conceptual coherence

	Coherence	Kinematics	1st Law, Diagram	1st Law Verbal	2nd Law	3rd Law	Kinds of Force	
							Gravitation	Contact
University	N	90	95	67.5	95	65	95	85

	P	10	5	32.5	2.5	30	5	15
	CC	0	0	0	2.5	5	0	0
Year IV	N	87.2	90.7	59.3	94.2	70.93	86	84.9
	P	12.8	9.3	39.5	5.8	29.07	14	15.1
	CC	0	0	1.2	0	0	0	0
Year I	N	88.4	88.4	68.1	95.7	85.5	95.7	79.71
	P	11.6	11.6	31.9	4.3	14.5	4.3	20.29
	CC	0	0	0	0	0	0	0

C. *Dominant misconceptions*

As described in the method of analysis section earlier, a misconception was considered dominant if it represented 50% of incorrect answers and if all groups of participants selected the same incorrect inventory item. The results obtained were as in Table VI.

Table VI
Dominant misconceptions among participants.

		University	Year IV	Year I
Q	Inventory item	Dom. In (%)	Dom. In (%)	Dom. In (%)
Impetus dissipation				
12	C	75	34.9	34.8
13	B	72.5	73.3	62.3
24	C	20	38.4	31.9
27	B	45	51.2	36.2
Ego-Centered reference frame				
14	A	75	57	58
Position-velocity un-discriminated				
19	D	62.5		
Velocity- acceleration un-discriminated				
20	C	47.5	39.5	39.1
Gradual/delayed impetus build up				
10	D	70	67.4	69.6
Largest force determines motion				
17	A	42.5	62.8	60.9
Circular Impetus				
5	C	45	37.2	53.6

6	A	52.5	51.2	49.3
7	A	22.5	14	15.9
18	D	50	-	-
Velocity proportional to applied force				
26	A	45	43	33.3
Greater mass applies greater force				
4	A	30	60.5	63.8
15	C	32	36	40.6
16	C	47.5	46.5	46.4
28	D	47.5	53.5	42
Heavier objects fall faster				
1	D	35	50	27.5
Acceleration implies increasing force				
3	B	72.5	55.8	50.7
Impetus supplied by hit				
11	C	-	-	55.1
30	E	60	48.8	52.2
Last force to act determines motion				
21	B	40	34.9	55.1

The percentages reflected in this table represent the highest frequencies of inventory items for individual questions.

Impetus

According to the *impetus* theory, impetus is an internal force which acts in the direction of motion and maintains the motion of an object independent of external agent. Clement (1982), and more recently Hubbard (2020) observed that this principle is used frequently by students to infer the existence of force in the direction of motion.

a. An impetus can be imparted by an applied force and transmitted from an object to another.
b. The impetus of an object is proportional to its mass and velocity, as expressed by the equation F = mv
c. An impetus may wear out or build up in the same way as the effect of an applied force.

These classifications of alternate conceptions regarding impetus appear to be dominant among the participants. From Table VI, four questions in FCI relate to *impetus dissipation.* All the participants, irrespective of groups, chose to answer the incorrect inventory item. Although varying percentages were obtained some even below 50%, but the fact that all groups chose the incorrect inventory item suggests that impetus theory plays a dominant role while questions regarding kinetic energy and momentum are asked.

Gradual/delayed impetus build up

Participants appears to be of the notion that once an object is set to motion, the impetus gradually increases for a sometime and then gradually decreases. Participants all across the groups chose the same incorrect answer, and further the dominant misconception percentages ranges from 61.9 % to 70%. Métioui and Trudel (2021) determined that Canadian pre-service teachers held misconceptions regarding impetus.

Circular impetus

Circular impetus was used as a basis to explain the persistent motion of the planet by the proponent of impetus theory (Buridan, 14 century). It implies that once a body is set into a circular motion, it tends to move in the circular direction, even when the path is broken. Tertiary groups of participants (University, Year IV and I) exhibited the presence of circular impetus misconception as shown in Table VI. Although the percentage of incorrect inventory item for class XI students did not exceed the threshold, 50%, most of the students chose the same wrong inventory item as the other three groups of participants.

Impetus supplied by a hit

The misconception was probed by two questions in the FCI. 55.1% of year I pre-service teachers chose an incorrect inventory item indicating a dominant misconception. However, in the second question, all groups of participants chose the same inventory item, and the dominant incorrect percentages were obtained from university (60 %) and Year I (52.2 %) participants. Therefore, impetus supplied by a hit also appears to be dominant.

Position-velocity un-discriminated and Velocity-acceleration un-discriminated

According to Halloun and Hestenes (1985), the most common and critical problem for students with respect to kinematical aspects of motion is the failure to discriminate between various kinematical quantities. This dimension is not so much a misconception, rather the inability to differentiate and integrate related kinematical concepts. 62.5% of university students maintained that two particles have the same speed when they simultaneously occupied the same position in a motion diagram, even if the particles were moving with different constant speed.

Similarly, when participants were asked to define the relation between two bodies moving with a constant velocity, where one object has a greater velocity than the other. All groups of participants chose an incorrect inventory item. Therefore, the tendency to not be able to discriminate related kinematical quantities appears to be dominant.

Interaction of forces

According to Maloney (1984), students characterize the reciprocal interaction between two objects by some sort of *dominance principle*, when Newton’s third law applied;

a) Greater mass applied greater force
b) The object which causes motion in the other exerts a greater force, because it overcomes other’s opposition.

Greater mass applies greater force

This misconception was probed by four questions in the inventory. As shown in Table VI, all groups of participants chose the same incorrect inventory item for all the questions. Although only four figures in the group are above 50%, overall, greater mass is perceived to apply greater force. This finding is similar to the misconceptions students held in Wells et al. (2020) study, with a sample of more than 3000 university students.

Largest force determines motion

Question 17 in the FCI probed for this misconception. Three groups of participants revealed dominant incorrect percentages ranging from 54.2 to 62.8. Moreover, all groups of participants appear to have the notion that largest force among two or more competing forces determines motion. Therefore, dominance principle appears to be a prevalent and dominant misconception. Wells et al. (2020) also reported that students held the misconceptions that the largest force determines motions.

Last force to act determines motion

From Table VI, 55% of Year I students held this misconception. However, the frequency of response in each group of participants was the highest for this incorrect inventory item. The possible origin of this Newtonian superimposition principle may be rooted in common sense belief, motion is determined by a compromise among competing forces. According to Halloun and Hestenes (1985), the superimposition principle is analogous to compromise, but students' conception of compromise involves impetus. The impetus supplied by the thrust, in this question 21, is taken to provide direction to the motion of the rocket, irrespective of the direction the rocket was initially moving.

Active forces

Analogous to Newton's Second law, the casual principle of motion states that every motion has a cause. This principle according to Halloun and Hestenes (1985), is characterized by the following two among others;

a) Acceleration is due to increasing force,
b) A constant force produces a constant velocity, sometimes expressed as F = mv.

Although the percentages of all the groups of participants did not exceed 50%, most of the participants in all the groups exhibited the common-sense alternative that velocity is directly proportional to the force applied. Also, substantial percentages of participants across all the groups (ranging from 50.7 to 72.5) are of the perception that when a body accelerates, the force acting on the body is increasing. Therefore, the casual principle of motion also appears to be a dominant misconception. Preservice teachers in Jordan were also harbour this misconception (Al-Rsa'i et al., 2020).

Heavier objects fall faster

The percentage incorrect answer was dominant only for Year I participants. However, in all groups it was registered that most of the participants held the misconception that heavier objects fall faster, when in free fall. Similar findings were reported among pre-service teachers in Indonesia (Syuhendri, 2019) and among high school students (Dognia & Dah, 2023).

Discussion

The objectives of this baseline study were to identify and delineate the dominant misconceptions and investigate the contextual coherence regarding the concept of force among Bhutanese students. From the overall sample, unfortunately, none of the participants have attained Newtonian thinker threshold (60% on the FCI) let alone the so called “confirmed Newtonian thinker or experts (85 % and above on the FCI)” according to Halloun and Hestenes (1995).

The search for contextual coherence in the FCI data did not yield any better results. Although several participants have reached contextual coherence in one or the other dimensions of mechanics, the percentages are non-substantial. In kinematics dimension none of the participants have reached contextual coherence. Similarly, Newton’s Second Law appears to be the dimension most affected by misconceptions. The percentages of all the four groups of participants with no contextual coherence obtained varied from 91.5 % to 95.7 %. From a physicist worldview, it is understandable that students who have difficulties in kinematics will not be able to master the concepts of Newton’s Second Law either. These two dimensions of mechanics are intricately linked by the concept of acceleration. Based on the percentages obtained for those who have attained contextual coherence in all the dimensions of mechanics, a lot must be done to attain a contextual coherence.

Dominant misconceptions were identified based on the benchmarks discussed earlier in the method of analysis section.

Implications for practice

The objectives of the research were to determine conceptual coherence and dominant misconceptions regarding the concept of force among higher education students. The findings of the research suggests that there exists several misconceptions and a lack of conceptual coherence regarding the concept of force. The instrument was used as a diagnostic tool to probe for students’ misconceptions in Newtonian mechanics and determine the extent to which students demonstrated conceptual coherence. The results have implications for policy and practices. A major concern is that classroom instructions appear not to have successfully addressed student’s alternative conceptions. Pre-service teachers and teachers should be cognizant of students’ misconceptions, its sources, and should possess a repertoire of strategies to address student misconceptions (Chen et al., 2020; Soeharto & Csapò, 2022). However, pre-service teachers themselves harbour misconceptions, which may be passed down to the students at a later date (Australian Council for Educational Research, 2011). Common sources of misconceptions are students, teachers, teaching learning resources, and context and teaching methods (Suprapto, 2020; Karpudewan et al., 2017). Addressing students’ misconceptions as they become evident during the teaching learning process or through a diagnostic assessment, prior to classroom instructions in Newtonian mechanics, may assist in curbing misconceptions. Using predict observe explain strategy to teach Newtonian mechanics have be found to effectively address student misconceptions (Astiti et al., 2020; Bunprom et al., 2019; Çalık & Bayçelebi, 2020).

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