Inventories of Basic Conceptions

Ibrahim A. Halloun

Educational reformists throughout the world have been calling lately for authentic assessment, i.e., for assessment that is integrated with learning and instruction in a way to facilitate student (and teacher) self-evaluation and self-regulation in the direction of meaningful learning of course materials. Meaningful learning is achieved in a given course when individual students develop, in productive ways, a coherent body of *conceptions*, *processes* and *dispositions* that make up the *student profile* targeted in the course. As such, meaningful learning is opposed to rote learning whereby students memorize by heart a bunch of statements and problem solving routines pertaining to various conceptions (concepts, laws, principles and other conceptual entities); statements and routines that students mechanically reproduce in course exams without necessarily understanding what the corresponding conceptions and processes are all about.

The Inventories of Basic Conceptions (IBC) are part of a battery of instruments already developed, or being developed, in physics and other fields of science and mathematics, to ascertain to what extent students actually develop meaningful rather than rote learning of course materials. IBCs target *basic conceptions* in a given field as outlined in the box below. The history of these inventories goes back to the Mechanics Diagnostic Test.

The Mechanics Diagnostic Test or MDT was first published in my PhD dissertation in 1984, and then in a joint article with David Hestenes in the *American Journal of Phys*ics in 1985. MDT evolved into the Force Concept Inventory or FCI (published by Hestenes, Wells, & Swackhamer, in *The Physics Teacher* in 1992, and revised in 1995 by Halloun, Hake, Mosca & Hestenes). The two standardized tests have been administered to tens of thousands of students around the world. The physics education community used them for a multitude of purposes, but most importantly for assessing student conceptual understanding of the basic concepts and principles of Newtonian mechanics, and subsequently for evaluating instruction.

In 2002, I began working on an *Authentic Assessment Framework* that integrates my work on Modeling Theory and on curriculum evaluation and development. In the process, and based on the two instruments' data, I analyzed the taxonomy, and subsequently the items, of both MDT and FCI. As a consequence, the Inventory of Basic Conceptions in Mechanics emerged that targets the *basic threshold* of meaningful understanding of Newtonian theory (cf. box below). The threshold corresponds in classical theory of mechanics to generic Newtonian concepts and principles, kinematical and dynamical, that students can develop in the context of the free particle model and the uniformly accelerated particle model.

Two IBCs followed, one for DC circuits, another for general physics. More IBCs will be developed in the future for a number of fields in science and mathematics.

In the following is an outline of key IBC features, along with a comparison between IBC-Mechanics and its predecessors, MDT and FCI. Ample details about these instruments and their assessment framework are available at www.halloun.net.

Evaluation of the quality of student learning and of instruction is a *normative* process, a process that needs to be done relative to clearly defined norms and standards. It involves, among others:

1. Establishing a detailed *taxonomy* of conceptions, processes and worldviews that would make up the profile that students are anticipated to develop following the completion of a given course/curriculum.
2. Setting *criteria* that establish whether individual students have actually developed each element of the anticipated profile, and to what extent they have done so.

In order for the evaluation process to focus on realistic aspects and result in meaningful outcomes, it is better that taxonomy and criteria be *graded*, i.e., that they be about ordered levels of student competency. At least two levels or *thresholds* need to be identified in this respect:

1. *Basic threshold*. This is the most fundamental level. It corresponds to the *minimum standards* of meaningful understanding that *any* student should meet following instruction, irrespective of the initial competence level and interests of the student.
2. *Mastery* or *critical threshold*. This is the highest threshold that students need to cross in order to master all fundamental conceptions and processes in a given course. In an ideal and truly equitable situation, all students willing to invest necessary efforts should be capable of reaching this threshold. In traditional classroom settings, critical threshold usually corresponds to the level of understanding of supposedly A-students.

A scientific theory consists, from our point of view of: (a) a set of models or families of models, and (b) a set of particular rules and theoretical statements that govern model construction and deployment and that relate models to one another and to specific patterns in the real world. A *scientific model* is a conceptual system mapped onto a specific *pattern* in the structure and/or behavior of some physical systems so as to allow us: (a) describe, explain, and predict (or postdict) the pattern in question, and, eventually (b) control or change physical realities exhibiting the pattern, and (c) reify the pattern in new realities (*cf. my publications on Modeling Theory*).

The *basic threshold* corresponds to conceptions and processes that are most elementary in the scientific theory that is the object of a given course, and that serve in the construction of the most elementary models of the theory. In classical (Newtonian) mechanics, basic threshold corresponds to conceptions needed for the construction of the free particle model and the uniformly accelerated particle model. The first model corresponds to physical objects at rest or in linear uniform translation under no net force in a given inertial reference system. The second model corresponds to physical objects that are in linear or parabolic translation under a net constant force in such a reference system. *Critical threshold* in classical mechanics corresponds to conceptions and processes that are indispensable for the construction and deployment of the two models just mentioned, as well as of at least the model of a particle in uniform circular motion and the harmonic oscillator model (*cf. my Authentic Assessment Framework*).

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The IBC name was first introduced with the Inventory of Basic Conceptions in Mechanics (IBC-Mechanics or IBCM) to stress the following:

"*Inventory*" because the instrument is intended to provide an account of student profiles with regard to a taxonomy that is as broad as it can get within the respective context and format.

"*Basic*" as relative to "basic threshold". This is the most fundamental level in *normative* evaluation. It corresponds to the *minimum standards* of meaningful understanding that *any* student is expected to meet following instruction, irrespective of the initial competence level and interests of the student. The threshold corresponds in classical theory of mechanics to generic Newtonian concepts and principles, kinematical and dynamical, that students can develop in the context of the free particle model and the uniformly accelerated particle model.

"*Conceptions*" include concepts, laws or any other conceptual entity in the make up of a naïve or scientific theory, as opposed to *processes* and *dispositions*. The three categories are fundamental constituents of a person's paradigmatic profile.

"*Mechanics*" rather than "force concept" because there is more to the instrument than just the concept of force.

IBC-Mechanics is meant to assess the themes laid out in the taxonomy table below. The following are some major features that distinguish IBCM from its predecessors (cf. comparative table below for more details):

1. *Breadth-depth balance*. The revised taxonomy concentrates on Newtonian theory within the context of only two basic models, free and uniformly accelerated particles. Matters are discarded that do not pertain to these models (e.g., the issue of centripetal and centrifugal forces in FCI items 5 and 18). This and the parsimony feature discussed next opened the way for deeper coverage of the six themes in the taxonomy (e.g., better attention to the "state of inertia" and the inclusion of the simultaneity issue in Newton's 3rd and 4th laws).
2. *Parsimony*. Sufficient effort has already been deployed in the community to establish the lack of coherence of student ideas regarding virtually any theme in introductory physics courses. Similar items that were originally meant in MDT or FCI to assess such coherence are avoided, thus making way for new themes in the taxonomy and the test.
3. *Attention to teachers' interests*. The two features above made it possible to attend for a broader spectrum of teachers' interests. In addition to entirely new issues in the taxonomy, MDT issues are reinstated that teachers had interest in and that were discarded in FCI. All in all, there are 8 new items in IBCM, 10 items originally figured in MDT but not FCI, 5 in both MDT and FCI, 8 in FCI but not MDT, and 2 in MBT.
4. *Reduction*. Items that used to address more than one issue in a single question are avoided (e.g., item 13 of the revised FCI used to address both upward and downward motion of an object tossed up in the air, whereas item 2 in IBCM addresses only the upward motion).
5. *Reliable distracters*. Alternatives of extremely low popularity are replaced with more popular/plausible alternatives (e.g., modified paths C and D in item 12 of IBCM).
6. *Clarity*. Stems and alternatives of some old items are rephrased so as to avoid distraction or confusion that some surveyed students and educators have been complaining about.
7. *Balanced distribution of correct alternatives*. Correct alternatives are distributed as follows in IBCM: 7As, 7Bs, 6Cs, 7Ds, 6Es, as opposed to 5As, 10Bs, 5Cs, 4Ds, 6Es in revised FCI, and 5(A, C, D, E)s and 9Bs in original FCI).

In addition to the above, IBC-Mechanics share by and large the same strengths and limitations of its predecessors (MDT and FCI). Perhaps the most important limitation that some may attribute to IBCM is that it does not offer students the chance to justify their answers. But again, like in the case of its predecessors, IBCM is a standardized test that is intended to offer a reliable snapshot of student ideas about basic conceptions of Newtonian mechanics and not a comprehensive view of such ideas and the reasons behind them. Such reasons have already been the object of many studies including our own (*cf. related publications on* www.halloun.net).

IBC-Mechanics Taxonomy Themes *(Fall 05-08)*	*Test Item**
1. *Law of Inertia (Newton's 1^{st} law)*	
The state of inertia of physical bodies is characterized with a constant velocity (that is not necessarily zero) in Galilean reference systems. No external cause, and more specifically no interaction, is needed to maintain such a state.	(10, 11, 20, 25, 31)
2. *Interaction and Force*	
No physical body can act on itself. An interaction takes place between at least two bodies, an « agent » (acting body) and an « object » (body acted upon) whose kinematical and/or dynamical state is being investigated.	25
The concept of force represents agent-object interaction. A force of particular characteristics is associated with a particular kind of interaction. These characteristics are not affected by the kinematical state of the object (current or past), or by the object interaction with other agents. In particular, motion does not imply force (impetus), and the force exerted by a given agent on an object does not build up or get used up because of the motion of the object.	2, 11, 14, (31)
The force acting on an object lasts as long as the interaction with the respective agent is taking place. It vanishes at the instant the interaction is brought to an end. The same goes for the force effect on the object.	(2, 19, 25, 33)
3. *Law of Interaction (Newton's 3^{rd} law)*	
Agent and object exert simultaneous forces on one another. The two exchanged forces are equal and opposite, irrespective of the physical or kinematical properties of either body.	22 23, 24
4. *Law of Cause and Effect (Newton's 2^{nd} law)*	
An object must interact with at least one agent in order to change its state of inertia, and more specifically to change the direction or the magnitude of its velocity.	(26, 27, 32)
The concept of acceleration represents the effect of interaction between agent and object. Acceleration and not velocity of object is proportional to the exerted force and inversely proportional to the object mass, and this irrespective of the nature of interaction.	28, 29, 30, 32
5. *Law of Composition (Newton's 4^{th} law) / Superposition Principle*	
Many forces can be composed only if exerted simultaneously on the same object.	19
Simultaneous interaction of a given object with many agents is identical in cause and effect: (a) to the absence of any interaction when the sum of all forces acting on the object is zero, or, otherwise, (b) to its interaction with a single agent that exerts on it a force equal to the vectorial sum of all forces exerted by the original agents.	20, 21, 31 17, (32)
The kinematical state of the object may be determined by the superposition of motions that it would have undergone, during the same period, under each dynamical state separately.	12, 16, (18, 26)
6. *State Laws*	
The kinematical state of a given object, from a particular moment onward, depends on the velocity of the object at this moment and its interaction with all influential agents. This state is independent of prior motion of either object or agents.	9, 10
Under the action of a constant force, an object maintains a uniformly accelerated motion following: (a) a linear trajectory when its initial velocity (at the time the force starts acting) is either zero or pointing in the (same or opposite) direction of the force, or (b) a parabolic trajectory when this is not the case with the velocity.	15, 27, 33 18, (12), 13, 26
The velocity of a uniformly accelerating object changes in proportion to the duration of motion and not to the distance traveled. For a given acceleration, duration of motion and velocity change are independent of the object mass. When the object slows down until a point where it turns around in the opposite direction, the object does not stop at this point; motion in both directions is symmetric and it takes place all along with the same acceleration.	1 5,6 3 4
Whatever their motion in a given reference system, two objects that occupy the same position at a given time do not have necessarily the same speed at this time. However, two objects may have the same acceleration when they move with different velocities.	7 8

* *Items between parentheses are shared with another theme to which they are more crucial*

Item	Answer	Origin*	Changes**
1	B	M2	Enhanced picture. Minor rewording.
2	A	M3	Alternatives rephrased to account for whether forces are constant or get used up.
3	B	New	
4	B	M4	Minor rewording.
5	A	F1	New alternative D and minor rewording of the rest.
6	D	New	
7	E	M1 / F19	None
8	A	F20	Alternative E replaced and other alternatives reordered.
9	C	M10 / F6	New paths B and D (curved, and then straight).
10	A	M11	Minor rewording.
11	D	M12	Alternatives reformulated.
12	E	F14	New paths A, C and D.
13	B	M14 / F12	Kicked puck instead of cannonball. New paths A and C.
14	C	M16	New alternatives.
15	C	M15	Alternatives rephrased.
16	B	M18	Alternatives rephrased.
17	A	M24	Stem rephrased. Alternative E moved up to A.
18	D	M25	Minor rewording.
19	A	New	
20	E	New	
21	A	B7	F_4 made horizontal. Minor rewording.
22	E	New	
23	C	F15	Stem reworded so that truck pushes car instead of the other way around. Alternative D replaced and other alternatives rephrased.
24	C	F16	
25	E	New	
26	D	M26 / F21	Alternatives D and E switched around.
27	D	M27 / F22	Minor rewording.
28	B	B21	Stem and alternatives reformulated.
29	E	New	
30	D	New	
31	C	F25	Rephrasing in line with other items on force inventory
32	D	F26	Minor rewording.
33	B	F27	Minor rewording.

* M = MDT (*AJP, 85*); F = FCI (95 revised version, *Mazur 97*); B = MBT (*TPT, 92*).

** Changes are relative to FCI when item figured originally in MDT and then FCI.