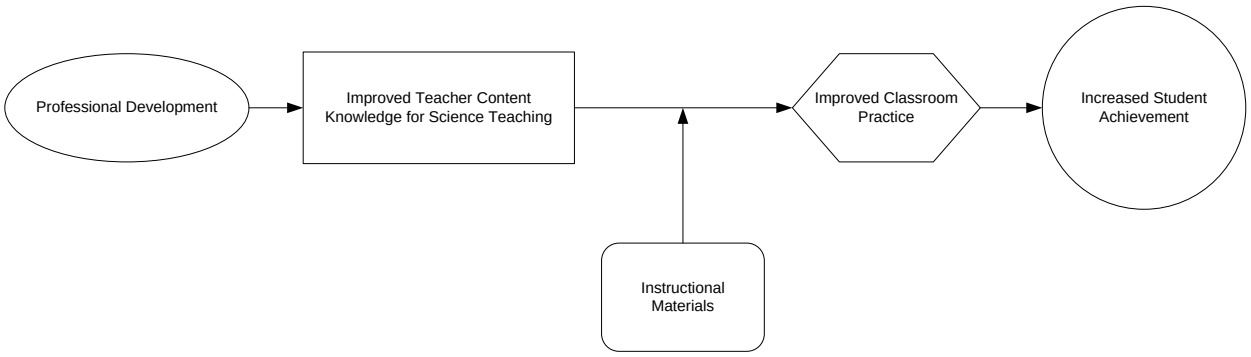
ATLAST Force and Motion Student Assessment
User Manual

1. Overview

The ATLAST Force and Motion Student Assessment is a 25-item multiple-choice assessment for middle grades students. The assessment measures understanding of the concept that "an unbalanced force acting on an object changes the object's speed, or direction of motion, or both" (American Association for the Advancement of Science/Project 2061, 1993). This user manual describes the background, development, measurement properties, and appropriate uses of the assessment. User manuals for other ATLAST assessments may be found at www.horizon-research.com/atlast.

2. Background

Horizon Research, Inc. (HRI) developed the ATLAST Force and Motion Student Assessment as part of a larger study. The project—Assessing Teacher Learning About Science Teaching (ATLAST)—was funded by the National Science Foundation under Grant no. DUE-0335328[1]. The goal of ATLAST was to develop instruments that researchers could use to study the theory of action that underlies much professional development for science teachers. Briefly, the model asserts that changes in teacher knowledge lead to changes in classroom practice (mediated by instructional materials), and ultimately, changes in student learning. (See Figure 1.) Despite the prominent role this model plays in professional development design, it has not been studied systematically, in part because of a lack of instruments. Among other products, ATLAST developed pairs of assessments—one for teachers and one for students—focused on the same science content. These pairs of assessments enable the study of relationships between teacher knowledge and student learning in specific science contexts. ATLAST assessments exist for three content areas: flow of matter and energy in living systems (photosynthesis and cellular respiration), force and motion (Newton's first and second laws), and plate tectonics.



[1] Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Figure 1
ATLAST Theory of Action

To enable large-scale research, HRI set out to create assessments that would be minimally burdensome, for both the test taker and the researcher. Accordingly, HRI opted for a multiple-choice format, recognizing the limitations of such items. For instance, well-constructed open-ended items may probe more depth of understanding than multiple-choice items, but they are more burdensome for both the researcher (in terms of scoring costs) and the test taker (in terms of time required to complete the assessment). In addition, scoring open-ended items requires the training of raters to establish inter-rater reliability.

3. Development of the Force and Motion Student Assessment

As described above, this development effort was part of a much larger and well-funded project, which afforded the luxury of a thorough development process. This process is depicted in Figure 2.

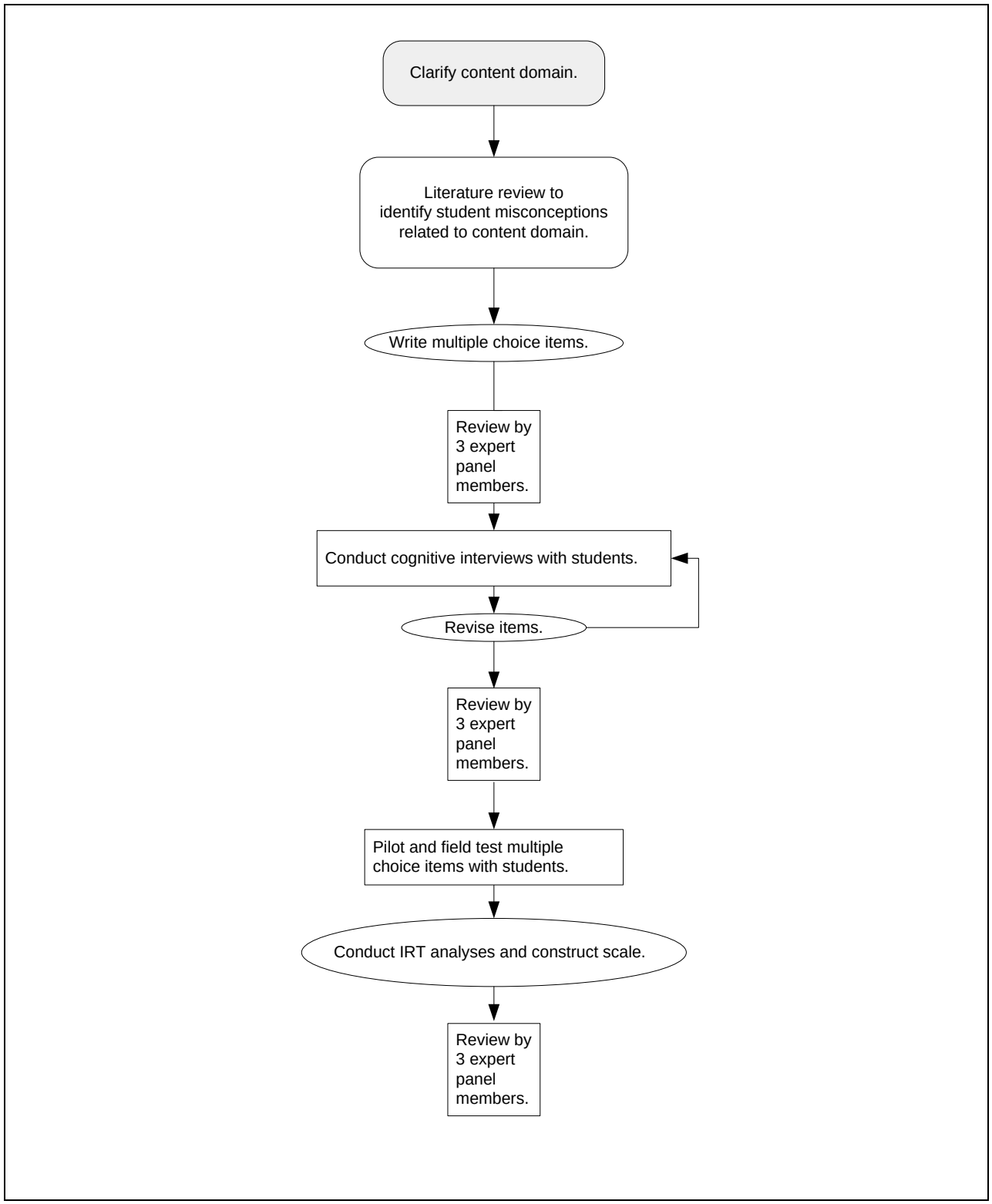


Figure 2
ATLAST Assessment Development Process

3.1 Clarifying the Content Domain

Development began with identifying the target content for the assessment, the idea that "an unbalanced force acting on an object changes its speed or direction of motion, or both" (American Association for the Advancement of Science/Project 2061, 1993). HRI specified the domain by "unpacking" this idea into 10 "sub-ideas," which were reviewed by four physicists/physics educators, resulting in minor edits. The final description of the content domain is shown in Table 1. Note that for students, the content domain includes only seven sub-ideas.

Table 1
Force and Motion Content Domain

Targeted Idea: An unbalanced force acting on an object changes its speed or direction of motion, or both.

Sub-ideas:

A. A force is a push or pull interaction between two objects, and has both magnitude and direction.
B. All of the forces acting on an object combine through vector addition into a net force; they either balance each other out (net force is zero), or act like an unbalanced force (net force is not zero).
    1. If the sum of forces exerted on an object in one direction is the same strength as the sum of forces exerted on the object in the opposite direction, then the forces on the object are balanced (i.e., the net force is zero).
    2. If the sum of forces exerted on an object in one direction is greater than the sum of forces exerted on the object in the opposite direction, then the forces on the object are unbalanced (i.e., the net force is not zero).
C. A force diagram uses arrows to represent the forces acting on an object at a particular moment. The length of the arrow represents the relative magnitude of the force. The direction of the arrow represents the direction of the force acting on the object.**
D. If an object is moving faster and faster, then there is a net force acting on the object in the same direction as the motion.
E. If an object is moving slower and slower, then there is a net force acting on the object in the direction opposite to the object's motion.
F. If an unbalanced force acts on a moving object in a direction that is neither in the direction of the object's motion, nor directly opposed to it, then the object's direction (and possibly speed) will change.*
G. If there is an unbalanced force acting on an object, the greater the strength of the unbalanced force, the greater the change in the object's velocity.**
H. If there is an unbalanced force acting on an object, the more massive an object is, the smaller the change in the object's velocity.**
I. If an object has constant speed in a straight line (or zero speed), then there is no net force acting on the object. This can occur either when:
    1. the forces on the object are balanced; or
    2. there are no forces exerted on the object
J. The force of friction acts to oppose the relative motion of two objects in contact. Friction acts on both objects along the surfaces in contact with each other. The magnitude of friction depends upon the properties of the surfaces and how hard the objects are pushed together.

* This sub-idea is included for completeness of unpacking, but it is not included in the assessment. Only motion in one dimension is addressed.

** These sub-ideas are for teacher only; they are not assessed at the student level.

3.2 Item Development

Development of the multiple-choice items began with identifying student misconceptions in the area of force and motion. We were able to utilize the rich research base on learning in force and motion; identifying student thinking related to this content area required an extensive literature search, but no original research was needed. An extensive list of student pre-conceptions and

misconceptions was gleaned from the literature, and then each area of difficulty was associated with one or more of the sub-ideas for force and motion. Figure 3 shows the student ideas associated with *one* sub-idea.

Sub-idea	**Student pre-conceptions and misconceptions**
If an object is speeding up, then there is a net force acting on the object in the same direction as the motion.	• Speed/velocity is proportional to the force acting. • Constant force produces constant velocity. • If a body is moving, there is a force acting on it in the direction of the motion. • Sustained motion requires sustained force. • Moving objects have a force in them that keeps them going. • Forces always act in the direction of motion. • If an object is speeding up, the force on it is becoming greater and greater.

Figure 3: A Force and Motion Sub-idea with Associated Research on Student Thinking

After identifying relevant student misconceptions, a months-long iterative process followed in which multiple-choice items were written and refined based on input from cognitive interviews with middle grades students. The interview protocol is shown in Figure 4.

Prologue:

We are developing test questions for middle school students who have been studying forces and motion, and we need your help to get the questions just right. I realize that you may not have studied some of this yet in school, and I don't expect you to get all of the answers right. If you get a few wrong, it will help me know whether we have written the answer choices well. You can ask me to explain any words or situations that may be unfamiliar or confusing, but I can't give you the answer to any of the questions until the end of the interview. Remember, the point is to help us write a good test, not to test what you do or don't know. You won't get a grade or anything like that on the test. Do you have any questions before we get started? If at any point in the interview you would like to stop, just say so.

Procedure:

- Ask student to read aloud and "think aloud" as they read the questions and answer choices, if they are comfortable doing so. Remind the student to go back and reread the question to himself/herself if he/she needs to. If reading the question aloud is too distracting or uncomfortable, allow the student to read the question to himself/herself.

- It is not necessary to time how long it takes for the student to arrive at an answer, but if it takes an especially long time on a question, please make a note of it in the comment area of the notes.

- For each item, ask:
  1. Why did you choose that answer? (probe for words or diagrams they keyed in on, as well as their thinking behind the response)
  2. What did you think of each of the other answer choices? (why?)
  3. Was there an answer choice you were expecting to see, but did not? What was it?
  4. Were there any words or diagrams you did not really understand, or situations that made the question confusing?
  5. Is there anything about the question that did not confuse you, but that you think might confuse other middle school students?

Figure 4
Cognitive Interview Protocol

An example student assessment item resulting from this process is shown in Figure 5.

A roller coaster is moving forward along its track in a straight line.

In which one of the following situations is the total force in the direction of the roller coaster's motion equal to the total force in the opposite direction?

A. The roller coaster moves at a constant speed.
B. The roller coaster moves faster and faster.
C. The roller coaster moves slower and slower.
D. The roller coaster moves faster and faster and then moves slower and slower.

Figure 5
Force and Motion Item

This item illustrates some features common to all ATLAST student assessment items. As mentioned previously, all are multiple choice. All include only four choices and preclude as choices "none of the above," "all of the above," or multiple correct answers such as, "A and B but not C."

3.3 Field Test

A pool of 34 force and motion student items were included in the pilot. Slightly fewer than 1,600 middle school students across the nation responded. The analysis of the data indicated that the items were overall quite difficult. Therefore, approximately 20 new and intentionally easier items were written as a result. These new and revised items were developed through the same process as the original items.

Using results from the pilot and the newly-developed items, 50 items were selected for the field test with just over 5,000 students nationally. As the pool of nearly 50 items was too large to administer in a single sitting, we created two forms with 32 items each; 16 items were common to each form.

For both the pilot and the field test, HRI recruited middle school science teachers to administer the items to at least one of their classes. The sample size for the field test was 4,883 students.

4. Measurement Properties of the Assessment

This section includes a description of the content coverage of the assessment, information about the validity and reliability of the assessment, and the results of the item-response theory (IRT) analysis.

4.1 Content Coverage

Using results from the field test, 25 items were selected for the final form. The distribution of items by sub-idea is shown in Table 3. The number of items totals to more than 25 because one item may address more than one sub-idea.

Table 3
Number of Items Addressing Each Sub-Idea

Sub-Ideas:	Number of Items
A. A force is a push or pull interaction between two objects, and has both magnitude and direction.	2
B. All of the forces acting on an object combine through vector addition into a net force; they either balance each other out (net force is zero), or act like an unbalanced force (net force is not zero).	4
D. If an object is moving faster and faster, then there is a net force acting on the object in the same direction as the motion.	1
E. If an object is moving slower and slower, then there is a net force acting on the object in the direction opposite to the object's motion.	5
I. If an object has constant speed in a straight line (or zero speed), then there is no net force acting on the object. This can occur either when the forces on the object are balanced or there are no forces exerted on the object	8
J. The force of friction acts to oppose the relative motion of two objects in contact. Friction acts on both objects along the surfaces in contact with each other. The magnitude of friction depends upon the properties of the surfaces and how hard the objects are pushed together.	6

Table 4 shows the answer key and content association for each item on the assessment. The letter "P" denotes a primary association with the sub-idea being targeted by the item.

Table 4
Answer Key and Sub-Idea Associations

Item #	Key	*A*	*B*	*D*	*E*	*I*	*J*
1	A					P	
2	A						P
3	C				P		
4	C		P				
5	A					P	
6	B						P
7	C			P			
8	C					P	
9	A		P				
10	D	P					
11	B					P	
12	C				P		P
13	D	P					
14	A		P				
15	C				P		
16	B					P	
17	D						P
18	A		P				
19	C					P	
20	A				P		
21	D						P
22	B					P	
23	A					P	
24	B						P
25	C				P		
	Total:	2	4	1	5	8	6

4.2 Validity

Three lines of evidence support the argument that the assessment is a valid measure of students' knowledge of force and motion ideas. First, cognitive interviews with students established that students interpret the items as intended and that students must use their knowledge of content to answer the items correctly. Second, a panel of three content experts (individuals with a Ph.D. in physics) reviewed the assessment items at three stages (see Figure 2) to ensure content accuracy. They also reviewed the final assessment and judged it to be an adequate measure of the content domain. Finally, dimensionality analyses (including both factor analysis and cluster analysis) indicate that both a both a 1-factor and a 2-factor solution were supported. We chose to use the 1-factor solution, with all items on the assessment measuring a single dominant trait. HRI termed this trait "content knowledge about force and motion."

4.3 Reliability

The assessment has an internal reliability of 0.85.

4.4 Speededness

In the field test, teachers were instructed to give their students 50 minutes or the length of the class period (whichever was shorter) to complete the test. There was no evidence of speededness.

5. Using the Assessment

The ATLAST Force and Motion Student Assessment is available at no cost to individuals who agree to certain terms of use. To request a review copy of the assessment, or to access the terms of use, visit http://www.horizon-research.com/atlast. The terms of use are also appended to this manual.

5.1. Appropriate Use

The ATLAST Force and Motion Student Assessment will yield a score for each individual. However, the assessment is not valid for making *judgments* about individuals based on those scores. For instance, assigning grades based on scores is not a valid use of the assessment. The assessment was not validated for such purposes.

HRI developed the assessment for use in research contexts involving groups of teachers. Appropriate uses with sufficiently large groups of teachers (20 or more) include:

- Measuring the change in group mean from pre-workshop to post-workshop;
- Comparing the gains of treatment and control groups; and
- Investigating the relationship between teacher knowledge and student learning.

5.2 Amount of Time Required to Complete the Assessment

Although there is no evidence of speededness, it is recommended that at least 45 minutes be allowed for completing the assessment.

5.3 Computing Scores

Scores may be computed either as number correct or percent correct. Results of an item-response theory (IRT) analysis are shown in Table 5. This table can be used to convert a raw score in terms of number correct to the corresponding scaled score. Raw and scaled scores representing mean values are presented in bold text.

Table 5
Assessment Score Conversions

Force and Motion Student Assessment			Raw Scores	
Raw Score	Scaled Score		Mean	SD
0	9		12.74	4.98
1	10			
2	12			
3	13			
4	18			
5	20			
6	26			
7	29			
8	32			
9	36			
10	39			
11	43			
12	47			
13	**51**			
14	55			
15	59			
16	63			
17	67			
18	74			
19	77			
20	80			
21	85			
22	89			
23	93			
24	96			
25	100			

References

American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy* (p. 418). New York: Oxford University Press.

Carlsen, W. (1999). Domains of teacher knowledge. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 133-144). Norwell, MA: Kluwer Academic Publishers.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95-132). Norwell, MA: Kluwer Academic Publishers.

Shulman, L. S. (1986). Those Who Understand: A Conception of Teacher Knowledge. *American Educator*, *10*(1), 9-15,43-44.

Veal, W. R., & MaKinster, J. G. (1999). Pedagogical Content Knowledge Taxonomies. *Electronic Journal of Science Education*, *3*(4).

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. *Review of research in education*, 173-209.

Terms of Use Agreement
Force and Motion Student Assessment

By using the ATLAST Force and Motion Student developed by Horizon Research, Inc. (HRI), you agree to abide by the stipulations below concerning use, test security, test administration, and citations.

Use of the Assessment

The Force and Motion Student Assessment may be used to gauge growth in knowledge about a specific content area as a result of instructional experiences.

We ask that you abide generally by the standards put forward in the *Standards for Educational and Psychological Testing* (AERA/APA 1999).

You may not use the assessment to evaluate individuals. Assessment results may not be associated with any high-stakes consequence such as grades. The assessments were not developed for making decisions/judgments about individuals.

You should also refrain from using these measures to publicly demonstrate students' ability or lack of ability in science, which may adversely affect willingness to participate in future studies.

IRB and/or District/School Study Approval

It is your responsibility to obtain proper IRB and/or the appropriate district/school approval for your study and to follow the necessary requirements for obtaining principal, teacher, parent, and/or student permission/approval to administer to the assessment(s).

Responsibilities to Teachers and Students

Your responsibilities to study participants will largely depend on the details of the IRB and/or district/school approval of your study. In most cases, completion of the assessment will be strictly voluntary. As such, participants should be informed of the voluntary nature of the study. Students should be assured that if their data are not anonymous, individual identities will be kept strictly confidential; i.e., an individual's score or responses will never be reported in association with his or her name or any other identifying information. To encourage a high response rate among teachers, it may be helpful to:

- Clearly explain what the data will be used for and why the data are important for your study;
- Explain that there are no high-stakes consequences associated with completing the assessment;
- If applicable, offer teachers compensation for time spent outside of the regular school day for administering the assessment.

Test Security

The ATLAST Force and Motion Student Assessment may NOT be shared without prior authorization from HRI. Anyone who administers the assessment must agree to:

- Refrain from using any non-released item in any presentation, paper, article, or other public forum. Items are expensive to develop and pilot, and we are attempting to keep our item pool secure.
- Refrain from distributing copies of any non-released item to individuals other than participants in your research project.
- Refrain from using the assessment, in original or in copied form, to provide test-taking practice or to enhance test-taking skills.
- Refrain from using test items, actual or similar, for discussion or review.

(HRI acknowledges that, in some cases, school administrators and IRBs may require that the test materials be reviewed prior to granting permission for study participants to take the test. Such a review is not considered a violation of this Test Security Policy as long as the other provisions of this policy are not violated.)

Citing ATLAST Assessments

In any writing in which data from HRI's ATLAST assessments are included, the following citation must be used:

The assessment was developed by the Assessing Teacher Learning About Science Teaching (ATLAST) project at Horizon Research, Inc. ATLAST is funded by the National Science Foundation under grant number DUE-0335328.

By signing below, I acknowledge that I have read the user manual, and I agree to abide by terms of use described above.

_____

Printed Name Signature Date

Address: _____

Street City State Zip code

Phone number (including area code): _____

Your email address: _____