

A Case Study Evaluating Students' Representational Coherence of Newton's First and Second Laws

Antti Savinainen

Kuopion Lyseo High School, Finland (antti.savinainen@kuopio.fi)

Jouni Viiri

University of Joensuu, Finland (jouni.viiri@joensuu.fi)

This paper presents a method to evaluate students' representational coherence, i.e. their ability to use multiple representations and move between them in the case of Newton's first and second laws. Results of five high school students are discussed.

Introduction

Many studies in fields other than physics education show that students often do not use multiple representations such as texts, pictures, or graphs effectively [1], and that they have difficulty moving across or connecting multiple representations. However, it has also been shown that the use of multiple representations in teaching has great potential benefits: for instance, the ability to use more than one representation deepens a student's conceptual understanding [2].

The importance of multiple representations has been realized also in physics education [3, 4, 5]. For instance, Hestenes [3] argues that students' ability to understand physics depends on the representational tools at their disposal. Meltzer's [4] preliminary results in physics suggest that there are possible discrepancies in student learning abilities when using oral and written representations compared with diagrammatic and mathematical representations. His results also suggest that certain representations may pose particular learning difficulties.

Conceptual understanding is one of the main goals for introductory students in physics. It involves an effective use of multiple representations: this is included in our characterization of students' conceptual coherence [6]. *Representational coherence* entails the unification of multiple representations based on correct conceptual understanding [7]: it means that the student is able to use multiple representations correctly and move between them. In this study multiple

representations consist of verbal, diagrammatic (free-body diagrams) and graphical representations. Mathematical representation is naturally very important but it is not within the scope of this study.

Our aim in this paper is to show how the representational coherence of five case study students was evaluated in the case of Newton's first and second laws. The focus is in presenting and discussing a way to probe and analyze representational coherence.

Data Gathering and Method of Analysis

To study representational coherence, five students (aged 16) were chosen from an introductory high school mechanics course taught by author AS. The students followed Interactive Conceptual Instruction (ICI) which entails conceptual focus, classroom interactions, the use of multiple representations, research-based exercises, and texts to promote conceptual understanding [8].

Data were collected in multiple ways to permit *methodological triangulation* on students' understanding. Two well-validated multiple choice tests were used to obtain information on students' conceptual understanding in the target domain. The Test on Understanding of Graphs- Kinematics (TUG-K; [9]) provides information about students' understanding of graphical representations in kinematics; the Force Concept Inventory (FCI; [10]) provides an overall measure of students' conceptual understanding of the force concept and related kinematics. Interviews provided more

direct data on students' representational coherence and reasoning while they apply multiple representations in the case of Newton's first and second laws (Newton's third law will be discussed elsewhere). Table 1 shows the timeline of the research instruments in chronological order.

Table 1. Timeline of the research instruments.

Research Instrument	Time
Pre-FCI	At the beginning of teaching
TUG-K	After teaching of kinematics
Post-FCI	After completing the teaching of the concept of force
Interview	A week after the post-FCI
Delayed Interview	4 months after the interview; 1.5 months after physics instruction (on momentum and oscillations)

Five students were chosen for interviews on the basis of their performance in the TUG-K test (top, middle and lower end students) after teaching of kinematics. The students were asked to 'to think aloud' while answering the interview questions. They were free to change their answers during the interviews if they wished so while some neutral questions were asked to clarify the students' views. The interviews were conducted by AS.

The interview and delayed interview questions in Figure 1 address mainly students' ability to use multiple representations and to some extent their ability to move between them. The representations involved in the interview questions are presented in Table 2. Students' results regarding Newton's laws in different representations were classified into three categories:

- I 'incorrect': essentially incorrect answer(s)
- II 'partially correct': part of the answer(s) correct with correct explanations
- III 'correct': question(s) answered correctly with correct explanations.

A student exhibits representational coherence if he/she reaches the highest category, III, in all the questions addressing the same physical principle within different representations. Students'

responses were analyzed separately by both authors to obtain *investigator triangulation*: classifications by the authors were in very good agreement with each other.

1. *Interview Questions* (derived from [11])
 A crate is inside a rocket which approaches the home base.

a) The rocket moves downward at *constant velocity*.

(i) Draw and label a free-body diagram for the crate. Explain.

(ii) What is the direction of the net force on the crate? If the net force is zero, state so explicitly. Explain.

(iii) Graph velocity against time.

(iv) Graph acceleration against time.

(v) Graph the net force on the crate against time.

b) As the rocket approaches its destination, its velocity decreases *uniformly*. (It continues to move downward.). [The same questions were asked as in case a)].

2. *Delayed Interview Questions* (derived from [12])
 A student in a lab holds a brick of weight G in her outstretched horizontal palm. She then starts to lift the brick vertically upward. All the following questions refer to the brick in the student's hand.

a) Explain the state of motion of the brick in terms of velocity and acceleration as described by the velocity against time graphs (below). The graphs show different periods of time for the state of motion of the brick. Upward direction is positive.

(i)

(ii)

(iii)

(iv)

b) Complete the corresponding acceleration and net force against time graphs. Explain what happens to the net force during the time interval shown in the velocity graphs.

c) Complete the corresponding free-body diagrams, i.e. draw the forces acting on the brick.

Figure 1. Interview and delayed interview questions.

Table 2. Classification of the interview questions in terms of Newton's laws and representations.

Conceptual Dimension	Representation		
	Verbal	Diagram	Graphical
Newton's First Law	1 a (ii)	1 a (i)	1 a (iii) - (v)
	2 a (i),(ii)	2 c (i),(ii)	2 b (i), (ii)
Newton's Second Law	1 b (ii)	1 b (i)	1 b (iii) - (v)
	2 a (iii), (iv)	2 c (iii), (iv)	2 b (iii), (iv)

Results

Multiple Choice Tests

The case study students' performance on the multiple-choice tests is presented in Table 3.

Table 3. Students' results of TUG-K, FCI, and normalized gains of the FCI ($\langle g \rangle$; [12]).

Stud.	TUG-K %	Pre-FCI %	Post-FCI %	$\langle g \rangle$
1	52	13	53	0.46
2	57	23	50	0.35
3	71	30	70	0.57
4	81	37	70	0.53
5	90	23	60	0.48

The TUG-K results of students 3, 4 and 5 imply that they had quite good understanding of graphical representations in kinematics. Post-FCI results indicate that the same students had crossed the limit of Newtonian thinking (60%) proposed by Hestenes et al. [13]. On the basis of the results it could be expected that students 3, 4 and 5 would do better in the interviews than students 1 and 2.

Interviews

All the interview and delayed interview questions on Newton's first law were very well answered (only student 3 made a mistake in one graphical representation). These results suggest that the students had reached representational coherence in Newton's first law. The results of different representations of Newton's second law in the interview questions are presented in Figures 2 - 3.

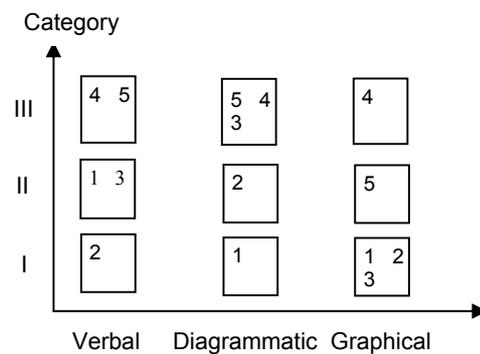


Figure 2. Interview: Students' categories in different representations of the second law.

In the first interview students did better in verbal and diagrammatic representations than in graphical representation (Figure 2). Only student 4 exhibited representational coherence in the second law. In general, students seem to have done better in the delayed interview (Figure 3) than in the first interview. This suggests that students' representational coherence in Newton's first and second laws had improved after the first interview. However, the students studied momentum and oscillations (these address the force concept) after the first interview: this probably fostered their representational coherence in the target domain.

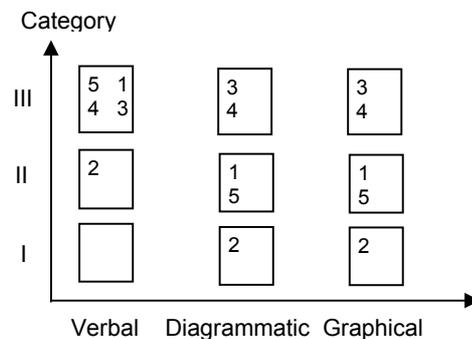


Figure 3. Delayed interview: Students' categories in different representations of the second law.

Four students gave a correct explanation in verbal representation in the delayed interview: they exhibited good integration between change of velocity, acceleration and net force. This integration, however, was not so good in the diagrammatic or graphical representation.

Discussion

The aim of this paper was to describe a method for studying students' representational coherence. The method seems effective in revealing students' strengths and weaknesses with multiple representations. With a larger number of students statistical testing could be used to compare results between the representations. The categorization and representation utilized in the figures could be useful in mapping students' representational coherence also in other areas of physics education.

Students' understanding of physics tends to be context dependent [e.g. 14]. The interview data on Newton's second law suggest that students' understanding also depends on representation: hence, our results lend support to Meltzer's findings [4]. It is clear that contextual factors cannot be fully eliminated when representational coherence is evaluated: constructing a free-body diagram, for instance, necessarily demands contextual information. To minimize the effects of context, all the interview tasks in this study were posed in one context at a time. This allowed us to study whether a student can apply a concept in one representation but fails in another, all other things being equal.

The FCI questions address various contexts or contextual features. It can be argued that the FCI measures *contextual coherence* within verbal and diagrammatic (e.g. motion maps) representations [6]. The probing of representational coherence cannot be isolated from contextual factors in the FCI, which is why it could not be used for the direct evaluation of representational coherence. It is noted that students' ranking in terms of normalized gains and the post-FCI results are in very good accordance with their ranking in the interviews. This is not very surprising, since the FCI thoroughly addresses the dimensions of the force concept [13]. However, the sample was too small to permit any generalizations.

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