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ABSTRACT

In their work in science and mathematics education, the authors have observed that students intuitively react in similar ways to a wide variety of scientific tasks. These tasks differ with regard to their content area and/or to the reasoning required for their solution, but share some common, external features. We have identified three types of intuitive responses: "More A-more B" and "Same A-same B" which relate to comparison tasks, and "Everything can be divided endlessly" which relate to repeated division tasks. For example, in respect to the first intuitive rule: "More A-more B", when students are told that Tom saves 15% of his salary, and Mary saves 20% of her salary, they tend to incorrectly claim that Mary saves more money than Tom, because 20 is larger than 15. This response is in line with the intuitive rule "More A (percentage) - more B (money)." Similarly, when presented with the task: Is the size of a muscle cell of a mouse larger than/equal to/ smaller than/ a muscle cell of an elephant, students tend to incorrectly argue that the cells of the larger animal are larger ("larger animal-larger cells"). Based on such observations, we developed the Intuitive Rules Theory. This theory explains and predicts students' common responses to science and mathematics tasks. Many responses that the literature describes as alternative conceptions could be interpreted as evolving from the intuitive rules. The intuitive rules theory is based on data collected in the western world. It is interesting and important from both theoretical an practical points of view to test the universality of this theory. For this purpose, a cross-cultural study was carried out with Israeli, Taiwanese and Aboriginal Australian elementary and secondary school students. A wide variety of comparison and repeated division tasks were given to the participants. Our findings indicate that Taiwanese and Aboriginal Australian students, much like Israeli ones, are strongly affected by the intuitive rules. Many students provided incorrect responses to the tasks, most of which were in line with the intuitive rules. Also, developmental trends were found to be similar. Consequently, we suggest that the intuitive rules are universal and affect students' responses in different countries in the same manner. Educational implications concerning the learning and teaching of science and mathematics in general and of specific concepts in particular will be discussed. In the lecture additional studies carried out in Jordan and Argentina are described. (Author/YDS)

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ARE INTUITIVE RULES UNIVERSAL?

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Abstract

In our work in science and mathematics education, we have observed that students intuitively react in similar ways to a wide variety of scientific tasks. These tasks differ with regard to their content area and/or to the reasoning required for their solution, but share some common, external features. We have identified three types of intuitive responses: "*More A - more B*" and "*Same A - same B*" which relate to comparison tasks, and "*Everything can be divided endlessly*" which relate to repeated division tasks. For example, in respect to the first intuitive rule: "*More A - more B*", when students are told that Tom saves 15% of his salary, and Mary saves 20% of her salary, they tend to incorrectly claim that Mary saves more money than Tom, because 20 is larger than 15. This response is in line with the intuitive rule "*More A* (percentage*) - more B* (money)". Similarly, when presented with the task: Is the size of a muscle cell of a mouse larger than/equal to/ smaller than/ a muscle cell of an elephant, students tend to incorrectly argue that the cells of the larger animal are larger ("larger animal - larger cells"). Based on such observations, we developed the Intuitive Rules Theory. This theory explains and predicts students' common responses to science and mathematics tasks. Many responses that the literature describes as alternative conceptions could be interpreted as evolving from the intuitive rules.

The intuitive rules theory is based on data collected in the western world. It is interesting and important from both theoretical and practical points of view to test the universality of this theory. For this purpose, a cross-cultural study was carried out with Israeli, Taiwanese and Aboriginal Australian elementary and secondary school students. A wide variety of comparison and repeated division tasks were given to the participants.

Our findings indicate that Taiwanese and Aboriginal Australian students, much like Israeli ones, are strongly affected by the intuitive rules. Many students provided incorrect responses to the tasks, most of which were in line with the intuitive rules. Also, developmental trends were found to be similar. Consequently, we suggest that the intuitive rules are universal and affect students' responses in different countries in the same manner. Educational implications concerning the learning and teaching of science and mathematics in general and of specific concepts in particular will be discussed. In the lecture we shall describe additional studies carried out in Jordan and Argentina.

Introduction

In our work in science and mathematics education, we have observed that students react in similar ways to a wide variety of conceptually non-related tasks (e.g., Stavy & Tirosh, 2000; Tsamir, Tirosh, Stavy, & Ronen, 2001). Although these tasks differ with regard to their content area and/or the type of reasoning required, they share some common, external features. So far three types of responses were identified, two relate to comparison tasks (*More A - more B and Same A - same B*) and one to repeated division tasks (*Everything can be divided endlessly).*

When relating to comparison tasks, students who were told, for example, that Tom saves 15% of his salary, and Mary saves 20% of her salary, tended to claim that Mary saves more money than Tom, because 20 is larger than 15. This claim is in line with the intuitive rule *More A* (percentage) - *more B* (money). Similarly, when presented with the task: Is the size of a muscle cell of a mouse larger than/equal to/ smaller than/ a muscle cell of an elephant, students tend to incorrectly argue that the cells of the larger animal are larger ("larger animal - larger cells"). These two tasks share some common features. In each of them two objects which differ in a certain, salient quantity A are described ($A_1>A_2$). The student is then asked to compare the two objects with reference to another quantity B (B_1 is not larger than B_2). In both cases a substantial number of students responded according to the rule *More A* (the salient quantity) - *more B* (the quantity in question) arguing, incorrectly, that $B_1> B_2$. Similar behavior was observed in many different tasks in different content domains in mathematics, physics, chemistry and biology.

When students are presented with comparison tasks in which two objects are equal in a certain quantity ($A_1= A_2$) but differ in another quantity (B_1 is not equal to B_2), they often claim that $B_1= B_2$ because $A_1= A_2$. Our claim is that such responses are instances of the intuitive rule "Same amount of A - same amount of B" (*Same A - same B*, in short). For example, when children were told that John saves 10% of his salary, and Donna also saves 10% of her salary, they tended to claim that John and Donna save the same amount of money. This response is in line with the intuitive rule *Same A* (percentage) - *same B* (money). Similarly. when presented with the task: "The common shapes of bacteria are spherical (cocci), rod-like (bacilli) and spiral (spirillae). The cell volume of these bacteria is equal. Is the resistance to dryness of these three types of differently shaped bacteria equal/nonequal? Explain your answer. If you think their resistance is different, which of these bacteria is most resistant? Why?" Students tended to incorrectly claim, in accordance with the intuitive rule "*Same A - same B*" that "the cells have the same volume therefore their resistance to dryness is the same". Such behavior was observed in many tasks related to science and mathematics.

With regard to repeated division tasks students were presented, for instance, with the following task: Consider a line segment, divide it into two equal segments, divide one (half) segment into two equal segments, continue dividing in the same way. Students were asked whether this process would come to an end and also to explain their answer. Similarly, students were asked to consider a copper wire undergoing the same process and to respond to the same question. It was found that the younger students (up to 15 years old) presented finite solutions to both tasks (this judgment is incorrect with respect to the line segment and correct with respect to the copper wire). The older students (15 years and up) tended to provide infinite responses to both the mathematical and material tasks, explaining that *Everything can be divided endlessly*. Similar results were obtained with other successive division tasks such as serial dilution, decomposition of radioactive material and repeated halving of biological objects

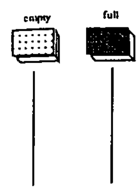
Based on such observations, the Intuitive Rules Theory has been proposed to explain and predict students' responses to mathematics and science tasks. We claimed that many of the responses that the literature had so far described as alternative conceptions could be interpreted as evolving from these intuitive rules, which are activated by specific external task features.

The intuitive rules theory is based on data collected in the western world. It is interesting, from both theoretical and practical points of view, to find out whether the intuitive rules are universal. Are they common characteristics of the human mind or a product of certain cultures and/or educational systems? This paper focuses on an initial examination of the universality of the intuitive rules. For this purpose, studies were carried out with Israeli, Taiwanese, and Aboriginal Australian students in an attempt to examine whether the intuitive rules similarly affect their responses.

Methods and Samples

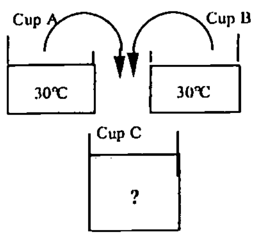
The Tasks

Comparison Tasks



Free Fall

Two matchboxes, one full of sand and the other empty, are held at the same height above the ground, in the same manner. They are both dropped at a certain point in time. Will the matchbox full of sand hit the ground before / at the same time / after / the empty matchbox? Explain your answer.

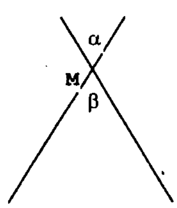


Temperatures

Consider the following drawing:

The water from Cup A and the water from Cup B were poured into Cup C. What is the temperature of the water in Cup C?

Explain your answer.



Vertical Angles

Consider the following drawing:

Is angle smaller than / equal to / larger than / angle ?

Explain your answer.

Volume of Cylinders

Take two identical rectangular (non-square) sheets of paper (Sheet 1 and Sheet 2):

Rotate one sheet (sheet 2) by 90¼

Is the area of sheet 1 smaller than / equal to / larger than / the area of Sheet 2?

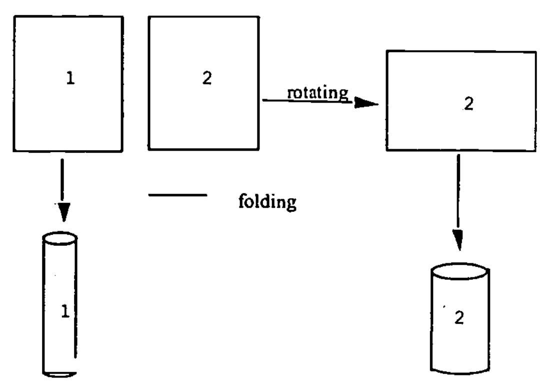
Explain your answer.

Fold each sheet (as shown in the drawing).

You get two cylinders: Cylinder 1 and Cylinder 2.

Is the volume of Cylinder 1 smaller than / equal to / larger than / the volume of Cylinder 2?

Explain your answer.



Repeated Division Tasks

Line Segment
Consider a line segment. Divide it into two equal parts. Divide one half into two equal parts. Continue dividing in the same way.
Will this process come to an end? Yes / No.
Explain your answer.

Copper Wire
Consider a copper wire. Divide it into two equal parts. Divide one half into two equal parts. Continue dividing in the same way.
Will this process come to an end? Yes / No.
Explain your answer.

Sugar water
A teaspoon of sugar is put into a cup of water and stirred well into it. Half of the sugar water is poured out, half a cup of water is added to the cup and is mixed thoroughly with the remaining sugar water. This is done again: Half of the sugar water is poured out, half a cup of water is added, etc. This process is repeated.
Is it possible that at a certain stage no sugar at all will be present in the cup? Yes / No.
Explain your answer.

The tasks were originally formulated in Hebrew. The persons who conducted the research in Israel were mathematics and science educators, who were familiar with the Intuitive Rules Theory. They were responsible for writing, editing, and administering the tasks, as well as for analyzing the data.

In order to use these tasks in Taiwan, a 10 weekly four-hour sessions workshop about the Intuitive Rules Theory was carried out by one of the authors. Forty-five Taiwanese mathematics and science educators participated in this workshop. They studied the theory and had to carry out a mini repetitive study in school classes. The tasks were translated into English, and then one of the workshop participants translated them into Chinese. In order to validate the translation, they commented on the translated version. The agreed upon version was again retranslated into English and the meanings were verified. Then, the tasks were administered by the workshop participants, in a printed questionnaire in several cities in Taiwan. The students responded in Chinese and the results were analyzed by each of the participants.

The English version was used on the Australian Aborigines.

Participants and Process
IN ISRAEL:
(a) Free fall: 186 students from Grades 8, 10, and 12 (33, 109, and 53 students respectively) answered a printed questionnaire;
(b) Temperatures: 120 students, from Grades 2, 3, 5, 6, 7, 8 (20 from each grade) were individually interviewed
(c) Vertical angles: 243 students from Grades 2, 4, 6, and 9 (69, 65, 70 and 60 students respectively) answered a printed questionnaire;
(d) Volume of cylinders: 375 students from Grades 1-6, and 10, 12 (40 students from each of the 1-6 grade level; 110 10th graders and 29 12th graders). In Grades 1-6, were individually interviewed, and the 10th and 12th graders were given a printed questionnaire;
(e) Line segment, Copper wire, and Sugar water: 76 students from Grade 10 answered a printed questionnaire.

IN TAIWAN:
(a) *Free fall*: 243 students from Grades 2, 3, 4, 5, 6, 10 (33, 34, 40, 36, 34, and 66, respectively) answered a printed questionnaire;
(b) *Temperatures*: 921students from Grades 2, 3, 4, 5, 6, 10 (33, 197, 210, 205, 209, and 67, respectively) answered a printed questionnaire
(c) *Vertical angles*: 966 students from Grades 3, 4, 5, 6, 10 (206, 339, 345, and 67, respectively) answered a printed questionnaire;

(d) *Volume of cylinders*: 1269 students from Grades 1-6, 10, 11 (28, 33, 34, 117, 443, 428, 65, and 121, respectively) answered a printed questionnaire;

(e) *Line segment, Copper wire, and Sugar water*: 67 students from Grade 10 answered a printed questionnaire.

IN AUSTRALIA:
Free fall, Temperatures, Vertical angles, Volume of cylinders: 64 Aboriginal students from Grades 2-3, 4-5, 6-7 8-9 (22, 19, 13, and 10, respectively) were individually interviewed by the researcher.

Results
COMPARISON TASKS

Free Fall
Almost all young, elementary-school students in Taiwan and Australia incorrectly answered, in line with the intuitive rule, that the heavier box would hit the ground first, because: The heavier- the faster. In secondary schools, about 50% of the Israeli, 45% of the Taiwanese and 90% of the Aboriginal Australian 9th grade students provided the same, incorrect response.

Temperatures
Most young elementary school students in the three countries, answered incorrectly, in line with the intuitive rule, that More A (amount of water) - more B (higher temperature). However, while in Taiwan and in Israel, high percentages of incorrect responses in line with this intuitive rule were observed until grade 4 or 5, respectively, in Aboriginal Australians such responses were very frequent until grades 6-7 (Figure 1).

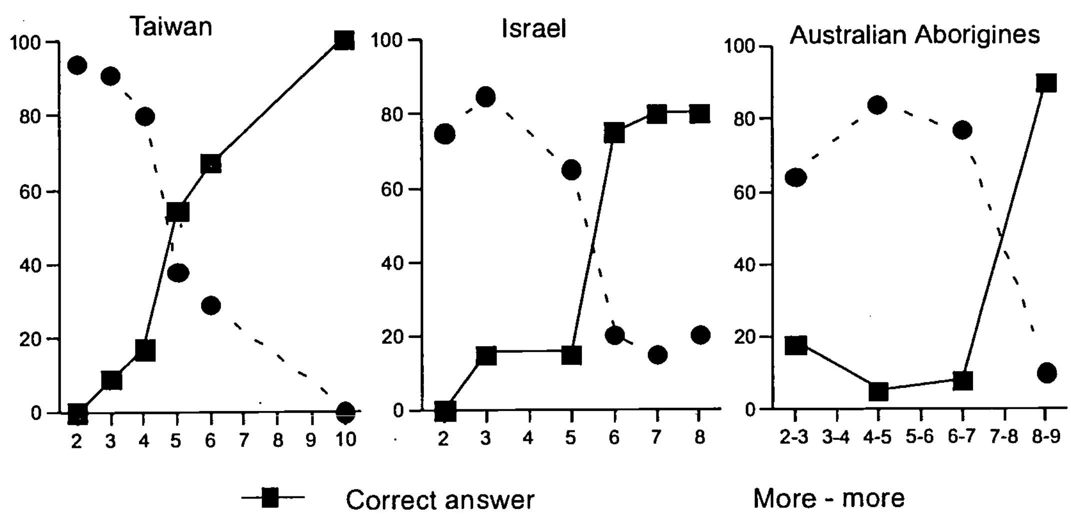


Figure 1: Distribution of correct and intuitive responses to the temperature task

Vertical Angles
Figure 2 shows that, once more, young students in the three countries, tended to incorrectly argue, in line with the intuitive rule More A (longer arms, larger enclosed area) - more B (larger angle). While only about 30% of the 3rd graders in Taiwan, about 10% of the 2nd graders in Israel and 5% of the 2-3 Grade Aboriginal Australians provided correct responses, most Israeli and Aboriginal Australians 9th graders (over 80%) and all Taiwanese 10th graders correctly responded that the angles were equal.

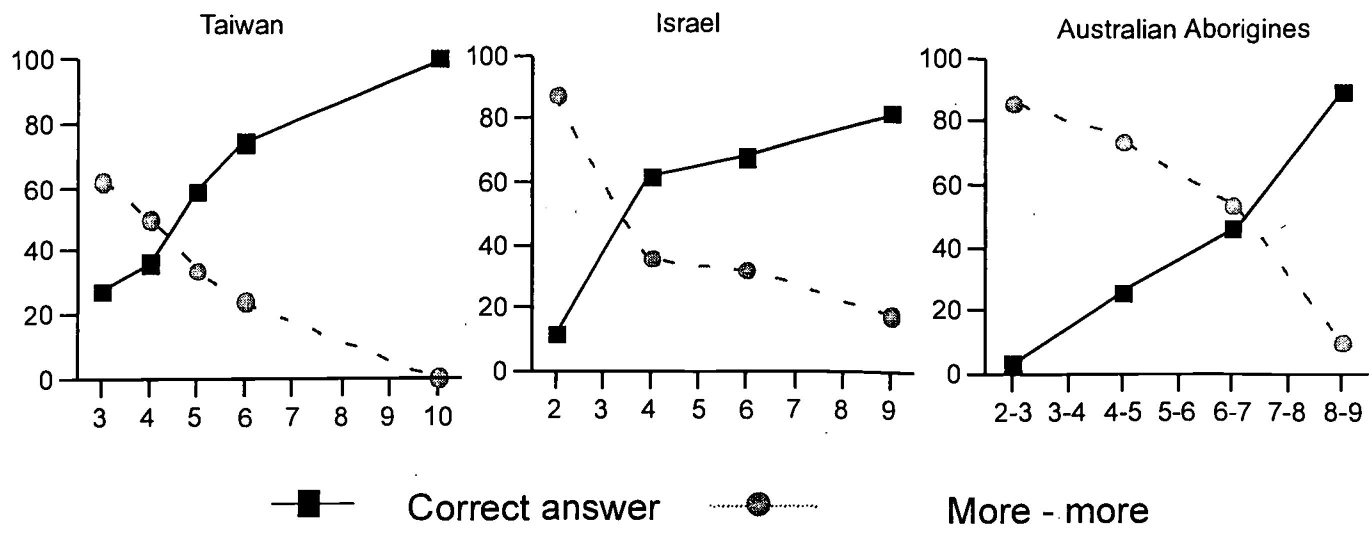


Figure 2: Distribution of Correct and Intuitive Responses to the Vertical Angles Task

Volume of Cylinders
The findings indicated that in all three countries the tendency to correctly answer the conservation of area task increased with age. It is interesting to note the increase, with grade, in all three countries, in the percentages of incorrect responses: Same A (area, paper) - same B (volume). This incorrect response developed in a parallel manner to the development of conservation of area (see Figure 3).

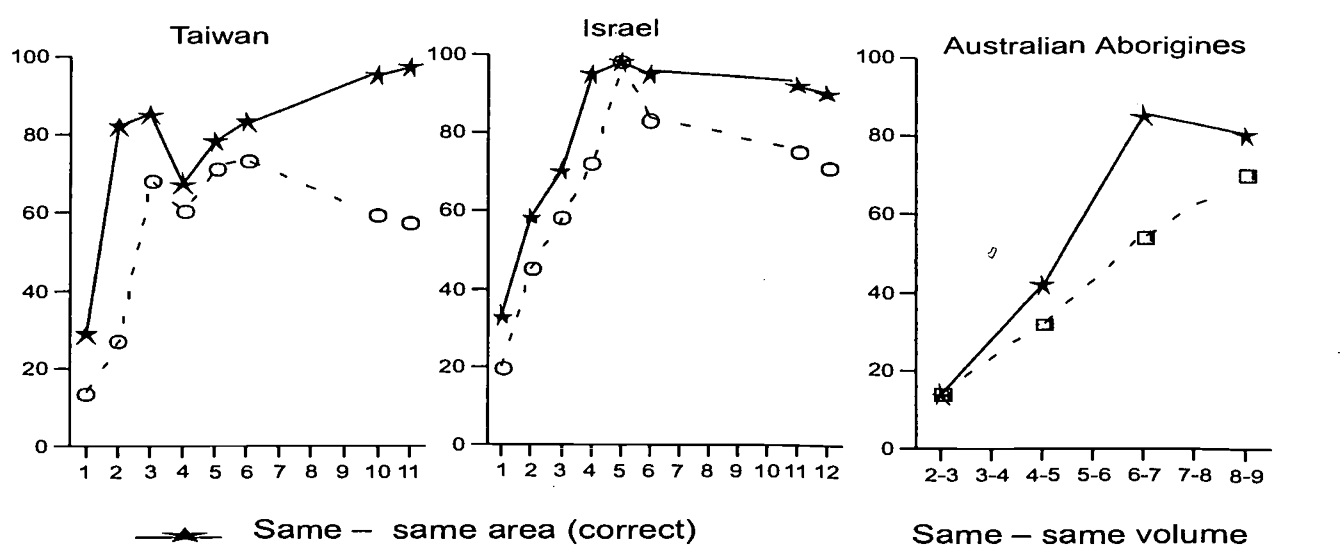


Figure 3: Distribution of "Equal" Responses to the Comparison of Area and Volume of Cylinder Tasks.

Repeated Division Tasks
Table 1 shows that the majority of 10th graders in both Taiwan and Israel tended to respond in line with the intuitive rule *Everything can be divided endlessly*. They correctly claimed that the repeated subdivision of the line segment could go on forever, but incorrectly claimed that the repeated subdivision of the copper wire will continue endlessly. With regard to the sugar water they incorrectly claimed that sugar would always remain sugar in the diluted solution. This response is an expression of the intuitive rule: *Everything can be divided endlessly* (Table 1).

Table 1: Students' Intuitive Responses to the Repeated Division Tasks (in %).

	Line segment	Copper wire	Serial dilution
Taiwan	69%	60%	83%
Israel	67%	50%	58%

Final remarks

The findings of this study clearly indicate that Taiwanese and Aboriginal Australian students, much like the Israeli ones, are strongly affected by the intuitive rules: *More A – more B* and *Same A - same B*, when presented with relevant comparison tasks. In relation to tasks where the correct answer was not in line with the intuitive rules, two main findings should be highlighted. First, for all tasks, two major types of responses were evident – a correct and an incorrect response, the latter in line with one of the intuitive rules. Also, the developmental patterns were rather similar. Differences were found with regard to the rate of developmental change. Consequently, we are able to suggest that the intuitive rules *More A - more B* and *Same A - same B* are universal. The differences in the developmental rate could be explained by cultural and/or educational differences.

Our findings related to the repeated division tasks indicate that Taiwanese and Israeli secondary school students are strongly affected by the intuitive rule *Everything can be divided endlessly*. The influence of this intuitive rule was also remarkable in these students' responses to the sugar water task. It should be noted that an attempt to examine the effect of this intuitive rule was carried out in a similar study in Germany (Buck, Stavy, & Tirosh, 1995). In this study, various repeated division tasks of material and mathematical objects were presented to 10th graders, including the line segment and the copper wire tasks. The findings indicated that about 70% of the participants correctly answered that the line segment could be endlessly divided, and about 50% of them incorrectly claimed that the copper wire could be endlessly divided as well. We are currently undertaking a replication of this study in Jordan and in Argentine. During the conference we'll report on the related results. Clearly further research is needed to enforce our knowledge about the universality of the role of the intuitive rules in students' mathematical and scientific thinking.

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Keywords: intuitive rules, cross-cultural study, comparison tasks, repeated division tasks, alternative conceptions

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