An investigation into the development of children's scientific reasoning with respect to floating and sinking

by Patricia Karsten

Abstract

In the context of floating and sinking of objects, the research investigated in how far children's scientific thinking develops autonomously in a process of discovery learning, and to what extent it can be fostered by an adult challenging children's ideas and giving support with structured tasks. The research was conducted as semi-structured interviews with two participants aged 7 and 12 who were presented with a number of objects, had to make predictions about floating or sinking and provide explanations. The predictions were tested and then discussed, pointing to observations that contradicted initial explanations. A scale was used to compare weight in relation to size of objects with the intent to further develop children's understanding. Analysis of children's explanations showed changing conceptions as a consequence of cognitive conflict in the discovery learning situation, and further advances in understanding when helped by an adult, but methodological problems should be resolved and tasks adapted before more general conclusions with respect to pedagogical concepts can be drawn.

Introduction

The research was based on Piaget's experiments to assess children's abilities in the context of his theory about stages of cognitive development (Piaget 1930). According to Piaget, children advance intellectually on their own through discovery learning, by analysing their real-world experiences and resolving cognitive conflicts resulting from contradicting observations (Nunes and Bryant 2006). This is opposed to Vygotsky's ideas about a zone of proximal development (ZPD) and the importance of an adult that acts as a tutor in helping the child to advance his understanding (Vygotsky 1978). In order to explain children's scientific thinking regarding floating and sinking of objects, Selley proposed that young children start out with explanations focusing on single object properties like weight or material, and begin to use air as explanation when objects do not behave as expected. When children are able to consider the relation of two variables, corresponding to Piaget's stage of formal operations, their explanations become more integrative (Selley 1993).

The investigation attempted at assessing the development of children's scientific thinking in light of these theoretical approaches in three phases. The first phase consisted in exploring children's initial ideas about floating and sinking by presenting typically behaving objects. The second phase created a discovery learning situation by confronting the children with objects that behaved atypical, with the intent to find out whether the children were able to resolve their cognitive conflict on their own by providing advanced theories, as proposed by Piaget. The third phase assessed the effect on children's theorizing if an adult scaffolded their reasoning by providing appropriate help, thus creating a ZPD in Vygotsky's sense. During the phases, children were asked to make predictions if the presented objects would float or sink. These predictions were tested by putting the objects into a water tank and children's explanations were discussed. The explanatory themes the children provided were coded and analyzed quantitatively as well as qualitatively.

The results of this investigation are supposed to shed light on the question whether children do best if allowed to autonomously develop theories in order to make sense of their observations, or if it is more advantageous to attribute a more active role to an adult accompanying their learning. The results also allow to consider in how far children's theorizing regarding floating and sinking follows the path proposed by Selley and thus might be useful when reconsidering pedagogical concepts in science courses.

Method

Design

The investigation was non-experimental and consisted in the detailed analysis of two semi-structured interviews based on a predefined protocol allowing to test and discuss children's theories about floating and sinking of objects. The interviews were conducted and video-recorded in March 2005 by an Open University Research team led by Prof. Terezinha Nunes (The Open University 2008).

Participants

With the help of a primary school in Oxford, the research team selected six children between 7 and 12 years on the basis of their willingness to take part in the study and be filmed during the interviews. In order to comply with BPS regulations for research with young children (BPS 2008), parent's written consent was taken, and children were assured they could end their participation at any time. The two interviews used for detailed analysis were that of a 7-year old boy, Samuel, and that of a 12-year old girl, Jessica.

Materials

To assess the children's understanding of floating and sinking of objects, 19 different objects were used, falling into the categories of light floaters, heavy sinkers, light sinkers, and heavy floaters. A medium-sized water tank served to test if objects floated or sank. To further develop children's understanding, two metal tins of different sizes, filled with lentils, and a simple plastic scale were used.

Procedure

The interviews followed a protocol that consisted in 9 stages, divided into parts A, B and C. Children were first introduced to the research idea and their task. Then in Part A, the children had to examine light floaters and heavy sinkers and make a prediction for floating or sinking, and were asked to provide explanations for their predictions (stages 1 to 3). In Part B, light sinker and heavy floater objects were assessed in the same manner (stages 4 to 6). Then in part C, based on beginning discussions in stage 6, children's ideas were challenged by discussing objects whose floating or sinking behaviour was inconsistent with initial explanations, and children were asked to find consistent explanations for their observations (stage 7). Stage 8 consisted in scaffolding children's thinking by comparing the weight of different objects with the scale, followed by the request do develop an integrative explanation for floating and sinking in stage 9.

Children's explanations were coded into classes of themes, distinguishing between stages 2, 5 and 6/7, and analyzed quantitatively as well as qualitatively.

Results

Both participants made highly successful predictions about floating and sinking of objects, with 84.2% correct answers, or 16 out of 19 objects. The younger participant erred on a heavy floater and two light sinkers, while the older participant erred on a light floater, a heavy floater and a light sinker (see Appendix, 'Participant's predictions').

For the younger participant, weight was the dominant explanatory idea for the initial stages 2 and 5 and accounted for 50% of all mentions, followed by material and size, both 11%. In stages 6/7, weight and size both lost relative importance in favour of explanations concerning shape (23.1%) and material (19.2%). For the older participant, weight (24.2%) and size (15.2%) were predominant as initial explanations. In stages 6/7, explanations shifted towards material (40%), solidity and unknown (both 10%). So both children relied on weight and size initially, but shifted to different main themes in stage 6/7: shape for the younger, material for the older participant (see Appendix, 'Ranking of themes').

When asked for summary explanations for floating and sinking in stages 6/7, the younger participant reconsidered his initial ideas and expressed why some objects might float while others sink, but at the same time realized the inconsistency of his explanations and suggested to 'ask a scientist'. The older participant gave explanations for groups of objects that relied mainly on material, but did not formulate a single explanation for both floating and sinking of all objects.

In the scaffolding phase (stages 8 and 9), the younger participant talked about the object properties 'squished up' as opposed to 'flat out', coming back to his ideas about the importance of size and shape, and explicitly formulated a theory for floating and sinking of objects, ignoring the previously observed inconsistency with a heavy floater, the grapefruit. The older participant reconsidered air as explanation for the tin objects and further discussed with Prof. Nunes the importance of mass and weight for weight comparisons of objects, but did not explicitly formulate an integrative theory for floating and sinking.

Discussion

There seem to be no age-related differences regarding the successfulness of predictions, and there were not enough objects to draw further conclusions from the different types of mistakes both children made. Children's difficulties in theorizing about floating and sinking despite their success in predictions confirm research findings that people learn physical laws through experience and apply them successfully, but without necessarily being able to theorize about them (Nunes and Bryant 2006; McClosky et al. 1980).

The dominant themes in the initial stages followed Selley's propositions with their focus on the single object properties weight, material and size. But in the later stages of the assessment, neither of the participants was able to consciously consider the relation of the two variables weight and size in order to explain floating and sinking, although their understanding advanced in the scaffolding phase. This might be because neither of the participants has yet reached Piaget's formal operations stage of cognitive development, but on the other hand we cannot exclude the possibilities of not enough time, inadequate scaffolding or difficulties with the psychological situation hindering children to further advance in their theorizing. Specifically the relational context of the assessment situation might have distorted children's behaviour and have lead to inadequate interpretation of their abilities (Perret-Clermont et al. 2006).

Samuel's final explanation confirmed observations formulated by Piaget that younger children have a tendency to discard evidence inconsistent with their ideas, rather than change their ideas (Nunes and Bryant 2006). Jessica's reasoning in the scaffolding phase supported the notion of greater ability for abstract thinking in older children, but at the same time pointed to the difficulties children have in applying theoretical knowledge to real-world problems, in this case using what she learnt about mass and density in science classes to explain her observations. Her difficulties support the theory that children have problems understanding intensive qualities that are measured as a ratio of two variables, in this case density as the ratio of weight and size (Nunes and Bryant 2006).

These results have to be seen in light of some methodological issues. Firstly, with the flow of the discussion during the assessment, the assessment protocol was not followed accurately, which led to incomplete and possibly biased data. For example in stage 5, no initial explanations were elicited for several items from the younger participant, leading to considerably less explanatory items in his data sheet (see Appendix, 'Frequency of themes'). Likewise, later explanations in stage 6/7 were not systematically elicited for all objects, leading to missing data for Part A objects for both participants. In view of the sensitivity of the quantitative results to categorization changes due to the small data base, it is possible that with complete data, other results would have been obtained.

Secondly, coding decisions for children's explanatory themes, as well as the interpretation of children's utterances for summary explanations during stage 6/7 and in the scaffolding phase are subjective, further adding to validity and reliability problems.

And finally, contrary to the more real-life character of objects in parts A and B of the assessment, the two differently sized tin objects filled with lentils in part C were rather artificial, which might have led to a 'strange situation' in Bronfenbrenner's (1979) sense, with the consequence of children performing below their abilities because the presentation of the task did not make human sense to them. This might lead to an underestimation of the potential of a pedagogical approach following Vygotsky's proposition of a ZPD.

Follow-up research should accurately follow its assessment protocol and take care to provide a complete data basis. It might also be fruitful to investigate different task designs for the scaffolding phase, in order to fully explore the potential of the ZPD approach, before more general conclusions can be drawn regarding the relative advantages of Piagetian discovery learning versus Vygotsky's ZPD scaffolding.

Conclusion

The research provided some evidence for Piaget's prediction that children are able to advance their scientific thinking autonomously, and also supported the idea that scaffolding them in a zone of proximal development in Vygotsky's sense helps them to develop their understanding, even though both children remained on the basic levels of theorizing according to Selley's path of hypotheses for floating and sinking.

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Appendix

- Coding scheme
- Participant's predictions
- Ranking of participant's themes
- Frequency of participant's themes
- Data sheets for the two participants
- Assessment protocol

Coding scheme

Code	Theme	examples/commentary
AIR	air inside	air inside ; traps air
ANA	object analogy	like a lemon ; like a ball ; sinks in Coca-Cola; like a human
DEN	density	simultaneous, integrated consideration of size and weight
FOR	forces	magnetism, upthrift
HOL	holes	has holes in it
LIQ	liquid inside	has juice inside ; has liquid inside
MAS	mass	
MAT	material	metal ; wood ; rubber
OBJ	object-specific	'grapefruit stuff inside' ;
SHA	shape	like a boat ; squished up ; flat out
SIZ	size	small ; large ; (not) much of it ;
SOL	solidity	it's solid; opposite might be soft, or like Jessica described the grapefruit as 'not thoroughly solid'
WEI	weight	heavy ; light ; water adds to weight
DON	don't know	

Participant's predictions

	Samuel		Jessica	
	f	%	f	%
total predictions	19	100.0	19	100.0
incorrect predictions	3	15.8	3	15.8
correct predictions	16	84.2	16	84.2
- in part A (of 9 obj.)	9	100.0	8	88.8
- in part B (of 10 obj.)	7	70.0	8	80.0
incorrectly predicted objects	large wood (HF), needle (LS), button (LS)		pencil (LF), dark wood (HF), needle (LS)	

f: frequency; HF: heavy floater; LS: light sinker; LF: light floater

Ranking of participant's themes

	Samuel		**Jessica**	
rank	**initial ***	**stage 6/7****	**initial**	**stage 6/7****
1	WEI (50.0)	SHA (23.1)	WEI (24.2)	MAT (40.0)
2	MAT; SIZE (11.1)	MAT (19.2)	SIZ (15.2)	SOL; DON (10.0)
3	AIR; ANA; HOL; SHA; SOL (5.6)	ANA; WEI (11.5)	DON (12.1)	AIR; WEI; HOL; MAS (6.7)
4	-	AIR; DON (7.7)	AIR; MAT; ANA (9.1)	SIZ; OBJ; ANA (3.3)
5	-	FOR; HOL; LIQ; SIZ; SOL (3.8)	HOL; SOL (6.1)	-
6	-	-	SHA; DEN; MAS (3.0)	-

*percentage values in parenthesis
**ranking in stage 6/7 includes data for objects from stage 2 where available

Frequencies of participant's themes: Samuel

Code	Theme	Initial	f	%	rank	Stage 6/7 - <u>without</u> objects from Part A	f	%	rank	Stage 6/7 - including objects from Part A	f	%	rank
AIR	air inside	x	1	5.6	3	x	1	4.3	5	+ x	2	7.7	4
ANA	analogy	x	1	5.6	3	xxx	3	13.0	3		3	11.5	3
DEN	density	-	0	0	-	-	0	0	-		0	0	-
FOR	forces	-	0	0	-	x	1	4.3	5		1	3.8	5
HOL	holes	x	1	5.6	3	x	1	4.3	5		1	3.8	5
LIQ	liquid inside	-	0	0	-	x	1	4.3	5		1	3.8	5
MAS	mass	-	0	0	-	-	0	0			0	0	-
MAT	material	xx	2	11.1	2	xxxx	4	17.4	2	+ x	5	19.2	2
OBJ	object-specific	-	0		-	-	0	0	-		0	0	-
SHA	shape	x	1	5.6	3	xxxxx x	6	26.1	1		6	23.1	1
SIZ	size	xx	2	11.1	2	-	0	0	-	+ x	1	3.8	5
SOL	solidity	x	1	5.6	3	x	1	4.3	5		1	3.8	5
WEI	weight	xxxxx xxxx	9	50.0	1	xxx	3	13.0	3		3	11.5	3
DON	don't know	-	0	0	-	xx	2	8.7	4		2	7.7	4
total			**18**	**100.0***			**23**	**100.0***			**26**	**100.0***	
items			**19**				**10**				**19**		

Frequency of participant's themes : Jessica

Code	Theme	Initial	f	%	rank	Stage 6/7 - <u>without</u> objects from Part A	f	%	rank	Stage 6/7- including objects from Part A	f	%	rank
AIR	air inside	xxx	3	9.1	4	-	0	0	-	+ xx	2	6.7	3
WEI	weight	xxxxx xxx	8	24.2	1	xx	2	8.7	3		2	6.7	3
SHA	shape	x	1	3.0	6	-	0	0	-		0	0	-
SIZ	size	xxxxx	5	15.2	2	x	1	4.3	4		1	3.3	4
HOL	holes	xx	2	6.1	5	xx	2	8.7	3		2	6.7	3
MAT	material	xxx	3	9.1	4	xxxxx xxx	8	34.8	1	+ xxxx	12	40.0	1
DEN	density	x	1	3.0	6	-	0	0	-		0	0	-
MAS	mass	x	1	3.0	6	xx	2	8.7	3		2	6.7	3
LIQ	liquid inside	-	0	0	-	x	1	4.3	4		1	3.3	
SOL	solidity	xx	2	6.1	5	xxx	3	13.0	2		3	10.0	2
DON	don't know	xxxx	4	12.1	3	xx	2	8.7	3	+ x	3	10.0	2
OBJ	object-specific		0	0	-	x	1	4.3	4		1	3.3	4
ANA	analogy	xxx	3	9.1	4	x	1	4.3	4		1	3.3	4
FOR	forces	-	0	0	-	-	0	0	-		0	0	-

total			**33**	**100.0***			**23**	**100.0***			**30**	**100.0***	
items			**19**				**10**				**19**		

*percentage rounding errors ignored

Data sheet for Participant : Samuel   Age : 7

Object	**Pred.**	**r/f***	**Initial explanation**	**Causal codes**	**Later explanation - Stage 6/7**	**Causal codes**
Light floaters	**Stage 2**					
1 Ball	F	r	air inside ; light (summary expl.)	AIR ; WEI	air inside	AIR
2 Pencil	F	r	quite light	WEI		
3 Wood (small)	F	r	quite light	WEI		
4 small candle	F	r	small (presented out of sequence for Sam)	SIZ	small; same material as the other candles	SIZ; MAT
Heavy sinkers						
1 Stone/rock	S	r	very heavy	WEI		
2 Metal lid	F/S	r	has walls like rubber dinghy, water can't get in; (would sink if water got in)	SHA; ANA		
3 Baked beans	S	r	very heavy as well	WEI		
4 Spanner	S	r	also heavy	WEI		
5 Skimmed milk	S	r	very heavy (presented out of sequence)	WEI		
Heavy floaters	**Stage 5**				**Stage 6/7**	
1 Wood (dark)	F	r	heavy but will float	WEI	like a human : floats when relaxed; heavy; wood; flat out;	ANA; WEI; MAT; SHA
2 Wood (large)	S	f	'not sure' about prediction, no explanation solicited	-	has flat bottom (tested then rejected); acts like a float or mat in swimming pool	SHA; ANA
3 Grapefruit	F	r	no explanation solicited	-	has juice inside ; has tiny holes where air gets in (like human skin); scrunched up but has air in which keeps it up; like hot air balloon;	LIQ; ANA; AIR
4 Candle white	F	r	no explanation solicited	-	summary explanation for candles : same material	MAT
5 Candle red	F	r	no explanation solicited	-	summary explanation for candles : same material; wider at the bottom (rejected idea);	MAT; SHA
Light sinkers						
1 Eraser	S	r	made of rubber; stiff ; not sure; [Prof. Nunes' proposition solid confirmed with yes]	MAT; SOL	solid; squished up	SOL; SHA
2 Penny	S	r	small and light but made of metal; metal can	SIZ; WEI;	light; don't know;	WEI; DON

			be quite heavy	MAT;		
3 Needle	F	f	no explanation solicited	-	gold/metal; quite light; heavier end carrying it down; magnetism (doesn't believe in this idea); not sure if metal property is relevant	MAT; WEI; SHA; FOR;
4 Elastic band	F	r	no explanation solicited [floated initially but sank when tossed by Prof. Nunes]	-	don't know	DON
5 Button	F	f	has holes in it	HOL	confirms holes theory: ditch inside but holes make it sink	HOL; SHA

*r: right, f: false

Data sheet for Participant : Jessica Age : 12 years

Object	**Pred.**	**r/f***	**Initial explanation**	**Causal codes**	**Later explanation - Stage 6/7**	**Causal codes**
Light floaters	**Stage 2**					
1 Ball	F	r	Air inside ; after test : nothing solicited	AIR	air inside	AIR
2 Pencil	S	f	not sure ; has lead inside ; don't know after test: not very heavy	MAT; DON; WEI		
3 Wood (small)	F	r	light ; after test : not as heavy as the water in the tank ; 'not as much' ; not sure; is made of wood like a boat and boats don't sink ; 'no holes' theory considered but rejected	WEI ; SIZ ; MAT ; ANA ; HOL	wood floats	MAT
4 small candle	F	r	not sure ; light after test : small and thin ; 'not much of it'	WEI ; SIZ ;	wax floats	MAT
Heavy sinkers						
1 Rock	S	r	very heavy ; after test : nothing solicited	WEI ;	rocks sink	MAT
2 Metal lid	F/S	r	depends on position ; boat shape when opening up ; air inside ; traps air when upside down; sinks on side because no air after test: like density but I don't really know	SHA; AIR; DEN; DON	traps air	AIR
3 Baked beans	S	r	air inside but too heavy to float; the tin has stuff inside that makes it so solid that it will sink ; after test: nothing solicited	AIR; WEI; SOL;	tin is made of metal (asked out of sequence)	MAT
4 Spanner	S	r	heavy ; more mass than water ; after test: heavy; 'there's quite a lot of it'	WEI; MAS; SIZ;		
5 Skimmed milk	S	r	no explanation solicited (presented in stage 5)	-	don't know	DON

Heavy floaters	Stage 5				Stage 6/7	
1 Wood (dark)	S	f	heavy ;	WEI	doesn't sink because it's wood ; wood is natural ; wood floats	MAT;
2 Wood (large)	F	r	no explanation solicited	-	wood floats	MAT ;
3 Grapefruit	F	r	don't know ; it's like a lemon and lemons float ; not sure;	DON; ANA	liquid inside; less mass than water; not completely solid; grapefruit stuff inside; like the ball; don't know;	LIQ; MAS; SOL; OBJ; ANA; DON
4 Candle white	F	r	no explanation solicited ; Prof. Nunes color explanation rejected	-	wax floats;	MAT
5 Candle red	F	r	bigger than small candle but wax makes it float	SIZ; MAT	wax floats;	MAT
Light sinkers						
1 Eraser	S	r	solid	SOL	solid; rubber sinks	SOL; MAT;
2 Penny	S	r	don't know ; sinks in Coca-Cola ; not sure	DON; ANA	very solid; has more mass than water; solid the whole way through; mixture of metals; metals sink.	SOL; MAS; MAT
3 Needle	F	f	small	SIZ	hole inside; made of metal and metals sink; not much of it ;	HOL; MAT; SIZ;
4 Elastic band	F	r	very light [floated initially but sank when tossed by Prof. Nunes]	WEI	sinks when wet because water adds to weight; rubber sinks;	WEI; MAT
5 Button	F/S	r	floates unless the water goes through the holes	HOL	has holes; water adds weight; don't know	HOL; WEI; DON

*r: right, f: false

Assessment protocol

Introduction

Part A : Initial understanding, typical objects (light objects that flow, heavy objects that sink)

1. Examination of objects
2. Predictions and attempted explanation
3. Testing predictions and comment

Part B : Initial understanding, unusual objects (light objects that sink, heavy objects that flow)

4. Examination of objects
5. Predictions and attempted explanation
6. Testing predictions and comment

Part C : Development of understanding

7. Inducing cognitive conflict –
    a. Objects where explanations are inconsistent
    b. Request to find comprehensive explanation
8. Scaffolding thinking
    a. Use of a scale to develop understanding (weight and size are both important)
9. Re-assessment of children's understanding
    a. Second request to find comprehensive explanation