The data sample was sufficiently large to enable analysis of frequency of response by groups and to compare changes in individual responses. The analysis of frequency of response was done using networks . This provided a tool which enabled some clarification and summarisation of the data to take place, together with a quantitative analysis. In addition, it provides a clear, visual representation of the main features of children's thinking at this age.

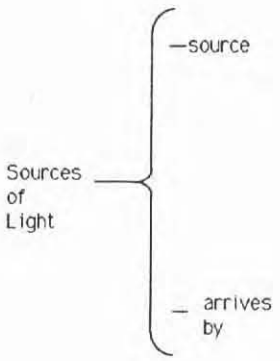
7.1a Sources of Light

Both elicitation activities had included questions about the origin of light. In particular, the questions asked were

> 'Look around the room. Where do you think the light is coming from?'
> 'Draw pictures of all the different things that you think can give off light.'
> 'How does light get here?'

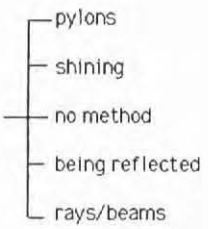
The wide-ranging responses about sources provided a large body of data about the way light travels as viewed by these children. These were summarised by using network analysis.

The essential method is to examine a large number of the responses and look for what categories of response emerge from the data. Children's ideas about sources were a clear feature of the responses and so it was decided to devote one network to these. In the network shown (Table 7.1), there are two predominant aspects to their responses; ideas about the sources of light and ideas about how light arrives. This is indicated by the use of an inclusive bracket called a 'bra' (Fig 7.1(a)). The use of the 'bra' indicates that any response of a child normally includes both aspects.



inclusive 'bra'
-mutually inclusive categories

Fig 7.1(a)



exclusive 'bra'
-mutually exclusive categories

Fig 7.1(b)

Recursive part of network i.e used more than once for each child

Fig 7.1(c)

A further division is then made for children's responses about how the light arrives and their ideas about sources. The division for their idea about the former uses an exclusive bracket called a 'bar' (Fig 7.1(b)). These responses are deemed to be so since children

who say that light gets here by pylons do not also say that it gets here by rays or beams. Included within this piece of the network is a separate terminal for children who give no indication of how light gets here.

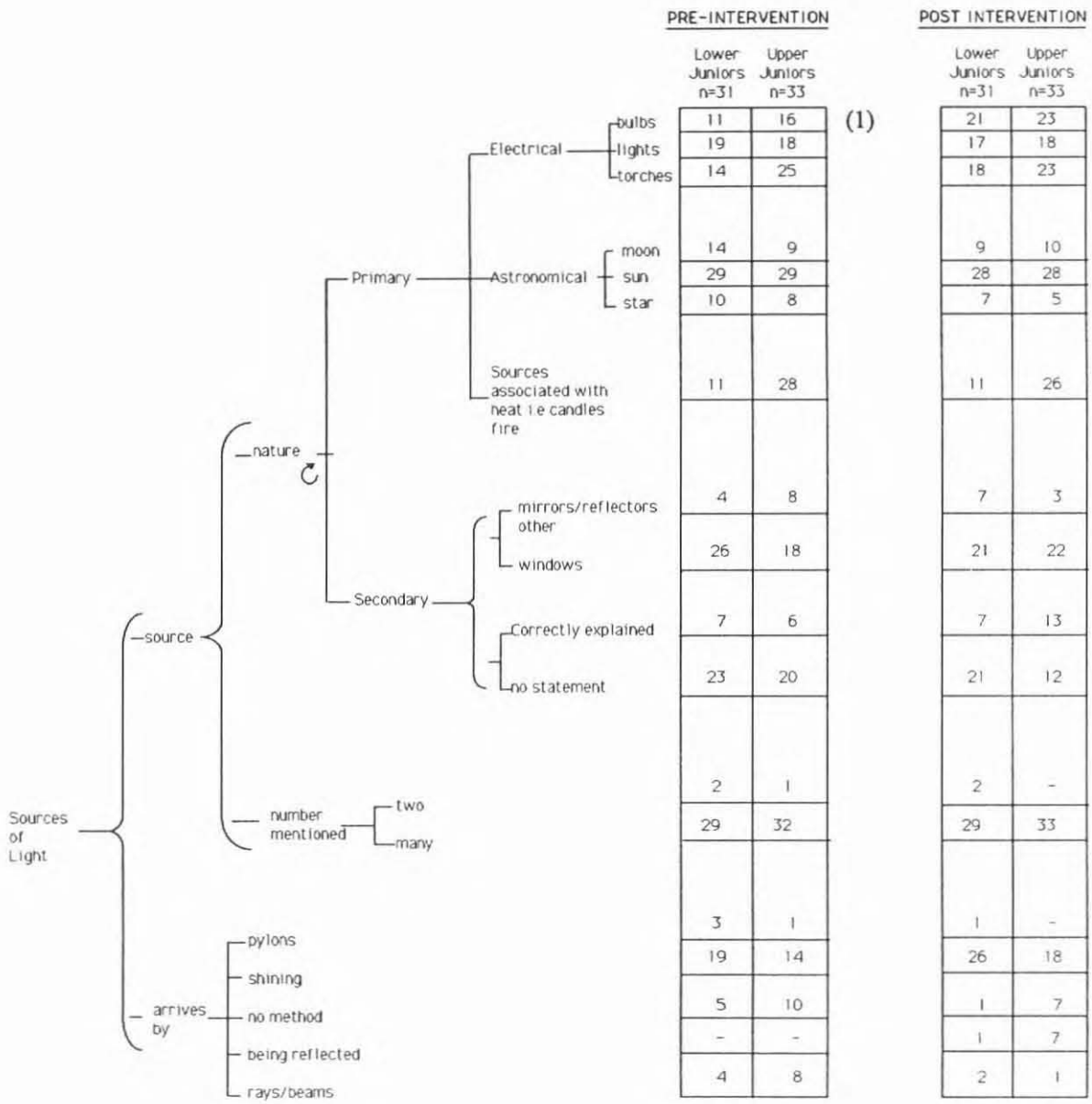
The network showing children's ideas about sources divides into two inclusive aspects by the use of a 'bra', which are ideas about the nature of the source and the number of ideas mentioned. The latter is necessary because children express or show more than one aspect of the nature of sources so this piece of the network is said to be recursive because it is used more than once. The recursive nature of this part of the network is indicated by the curled arrow (Fig 7.1(c)).

The network for the nature of sources subdivides into an exclusive bar. This is because the data item being looked at represents either a primary or a secondary source but not both. Further subdivisions are then made about primary sources which are exclusive. The subdivisions for the secondary sources are inclusive (shown by the use of a 'bra') and reflect aspects of the children's response.

The ends of the networks are known as terminals. Hence in Table 7.1, the category, 'bulbs' and the category 'pylons' are both examples of terminals. The increasing layers of sub-division within the network are referred to as the increasing 'delicacy' of the network. Such networks are an instrument for data analysis and reflect the view of the researchers. For example, the division between primary and secondary sources is not made by the children and simply provides one perspective for viewing the data.

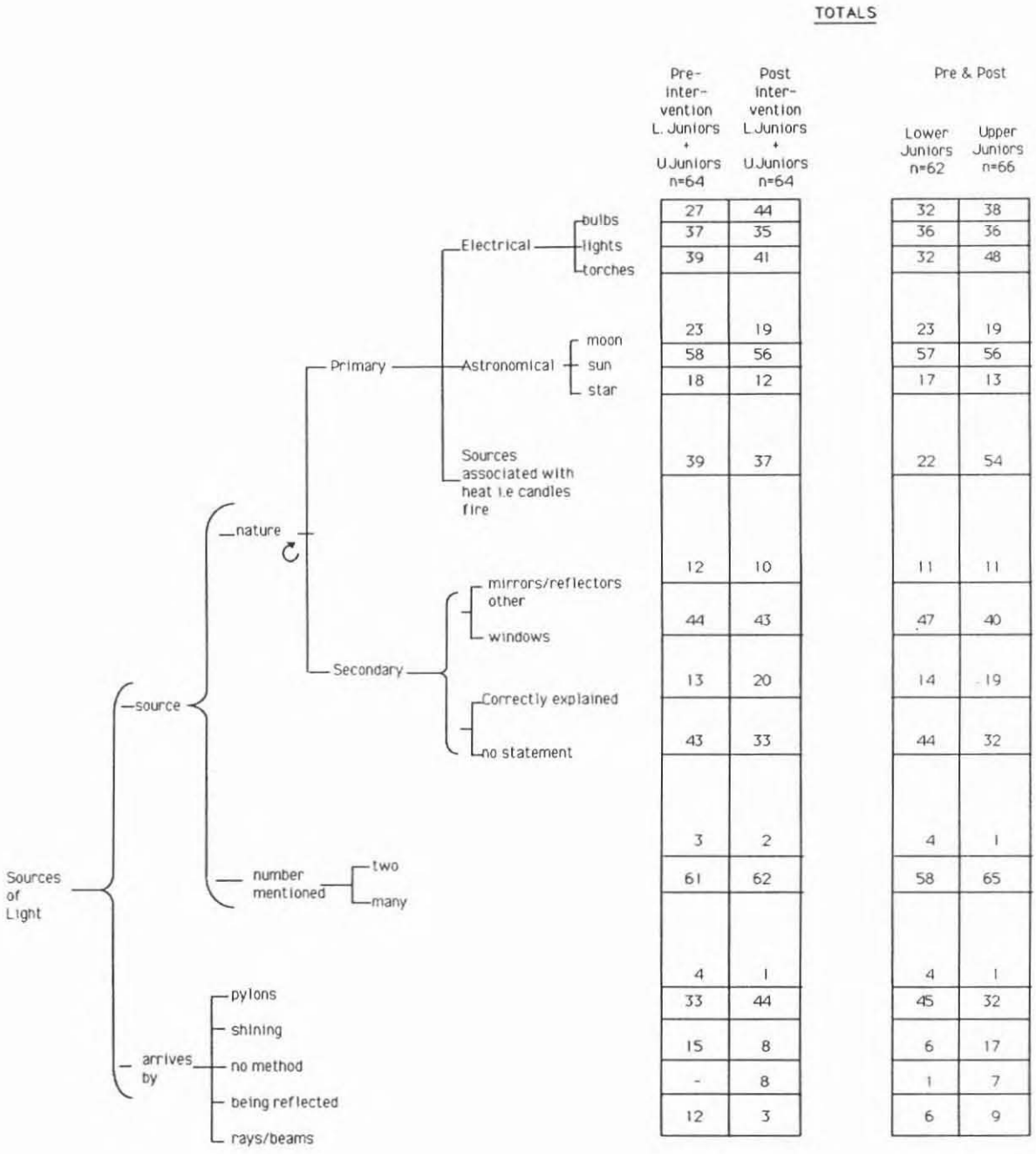
Each response is then coded. For example, the response shown in Fig 5.1, would require a tick in the following terminals: Bulbs, lights, torches, moon, mirror, fire. If the child, then explained how the mirror was a source of light by saying it was able to reflect light, the terminal 'correctly explained' would have been ticked, otherwise a tick would be placed in the terminal 'no statement'.

Table 7.1: Network analysis for children's ideas of sources of light showing results for the intervention



[1] Figures in Table 7.1 show the total number of instances for each terminal of the network

Table 7.2. Network analysis for children's ideas of sources showing figures for totals.



Figures in Table 2 show

a. Total for all children pre- and post-intervention.
b. Figures totalled for lower juniors (pre and post-intervention) and upper juniors (pre- and post-intervention).

This network shows two essential features of children's understanding of light sources. Firstly that the sources can be distinguished into primary and secondary sources. Asked to draw 'anything that gives off light', the children predominantly drew primary light sources. Asked 'where is light coming from', children provided responses that show an awareness of secondary sources such as window, mirrors and the ceiling. Only rarely did they offer an explanation of where the light for the secondary source originates i.e 'The light is coming through the windows from the sun.' Statements about secondary sources were normally limited to 'from the windows'.

The second feature of the network is a summary of the responses that children gave to the question 'How does light get here?'. The predominant response here was that objects 'shine' or 'shine down' with no overt recognition of something which travels. The use of the term 'shines' implies a causal recognition of the source of the light i.e the sun causes the light by shining rather than a recognition of a mechanism of transference.

The figures in Table 7.1 and 7.2 are the actual numerical values and show some interesting features. Firstly, nearly all pupils are aware of a wide variety of sources of light. The sources indicated were predominantly primary sources as this summary shows

Table 7.3. Total Number of Primary and Secondary Sources indicated

	Pre-Intervention		*Post-Intervention*	
	Lower Juniors (n=31)	Upper Juniors (n=33)	Lower Juniors (n=31)	Upper Juniors (n=33)
Number of instances primary sources shown	108	133	111	134
Mean number of primary sources shown per individual	3.5	4.0	3.6	4.0
Number of instances secondary sources shown	30	26	28	25
Mean number of secondary sources shown per individual	1.0	0.8	1.0	0.8

These summary figures indicate there was remarkably little variation in the mean number of sources of light indicated by children before and after the intervention. In

addition, the average figures show that children found it easy to indicate a reasonable number of objects which are sources of light and there is little difference between lower and upper juniors. Upper juniors did volunteer more sources but the difference was small and the intervention produced no significant change in this.

Primary sources were mentioned by children 3-4 times more often than secondary sources. However, an examination of Table 7.1 and 7.2 shows that the most common sources mentioned by children was the sun, which was mentioned by a minimum of 85% for any one sample. Other common sources mentioned were torches (minimum 45% of sample) and windows (minimum 55% of sample).

Some further insights can be gained by examining the totals for variation between the elicitation prior to the intervention and post intervention and any variation between responses obtained from totalling the responses from lower juniors and upper juniors. Analysis of the data from this perspective provides and indication of any significant differences that occur between these two groups regardless of the intervention. Table 7.2 shows the figures obtained by totalling the scores in this manner. The figures were tested for statistical significance by the various groupings.

Table 7.4: Statistical significance of changes.

	Significant change in the elicitations after the intervention by:			*Overall differences between Lower Juniors & Upper Juniors*
	Lower Juniors	Upper Juniors	Total	
bulbs shown as sources	$p < 0.05$	-	$p < 0.01$	-
torches shown as sources	-	-	-	$p < 0.05$
heat sources	-	-	-	$p < 0.01$
no statement about secondary sources	-	$(p < 0.05)$[1]	-	$(p < 0.05)$
Light arrives by shining	$p < 0.05$	-	$p < 0.05$	$(p < 0.01)$
No method	-	-	-	$p < 0.05$

1 Figures shown in brackets represent significant *decreases.*

Although table 7.4 shows that some of the changes were significant, it is notable that there are more significant differences associated with the change in age range than the intervention. The important point is that for a large number of categories for the network, *there has been no significant change*. One explanation would be that children's ideas about sources of light are well developed and rooted in commonplace observations of light coming from a wide range of primary sources. This would account for the preponderance of primary sources mentioned. Everyday observations do not recognize secondary sources or their nature which would possibly explain why statements about the source of light for mirrors and windows were relatively rare in both groups.

The positive effects of the intervention were very limited. This was not surprising as the preliminary data had already shown that children were familiar with a wide range of sources and it was felt that there was little that could be done to increase their awareness in the time available. Consequently the intervention phase did not primarily address this area of understanding. It is promising that more children can provide some explanation of secondary sources and talk about light 'shining' but given the small numbers, it is best to be sceptical about placing much emphasis on this result.

More interesting was the difference between responses from lower juniors and upper juniors. There were more natural significant differences found between these two groups than as any consequence of the intervention. Apart from fewer upper juniors who explained the arrival of light by shining, they were all positively weighted changes towards a more elaborate model of sources and how light travels. This would suggest that there is some experiential development with age, though it is important to note again that for the majority of categories, there is no significant change.

Summary: *The evidence can be summarised as follows.*

a. *Young children show an awareness of a wide variety of sources of light. The sources shown are predominantly primary sources.*

b. *There is some evidence that older juniors have a more complex model of sources which incorporates a recognition of secondary sources of light. Most of this difference can be explained by experiential developmental change rather than any effect of this study.*

c. *The most noticeable feature shown by the data is that there is very little change in children's understanding of sources of light as a result of this intervention.*

7.1b Representations of Light

Many of the elicitation activities called on children to use drawings to provide an explanation of what was happening in the activity or how they achieved a set task. The most notable feature about these tasks was the wide variation in the representations used by children to show what was occurring. These activities were, showing how they were able to see a torch in a mirror; showing how they saw the light from a candle; explaining how they saw a book to their younger brother/sister and showing how they saw a clock on the wall. Children were encouraged to use drawings in their explanations because this was found to be a productive method of obtaining answers from children about their ideas through a familiar mode of expression.

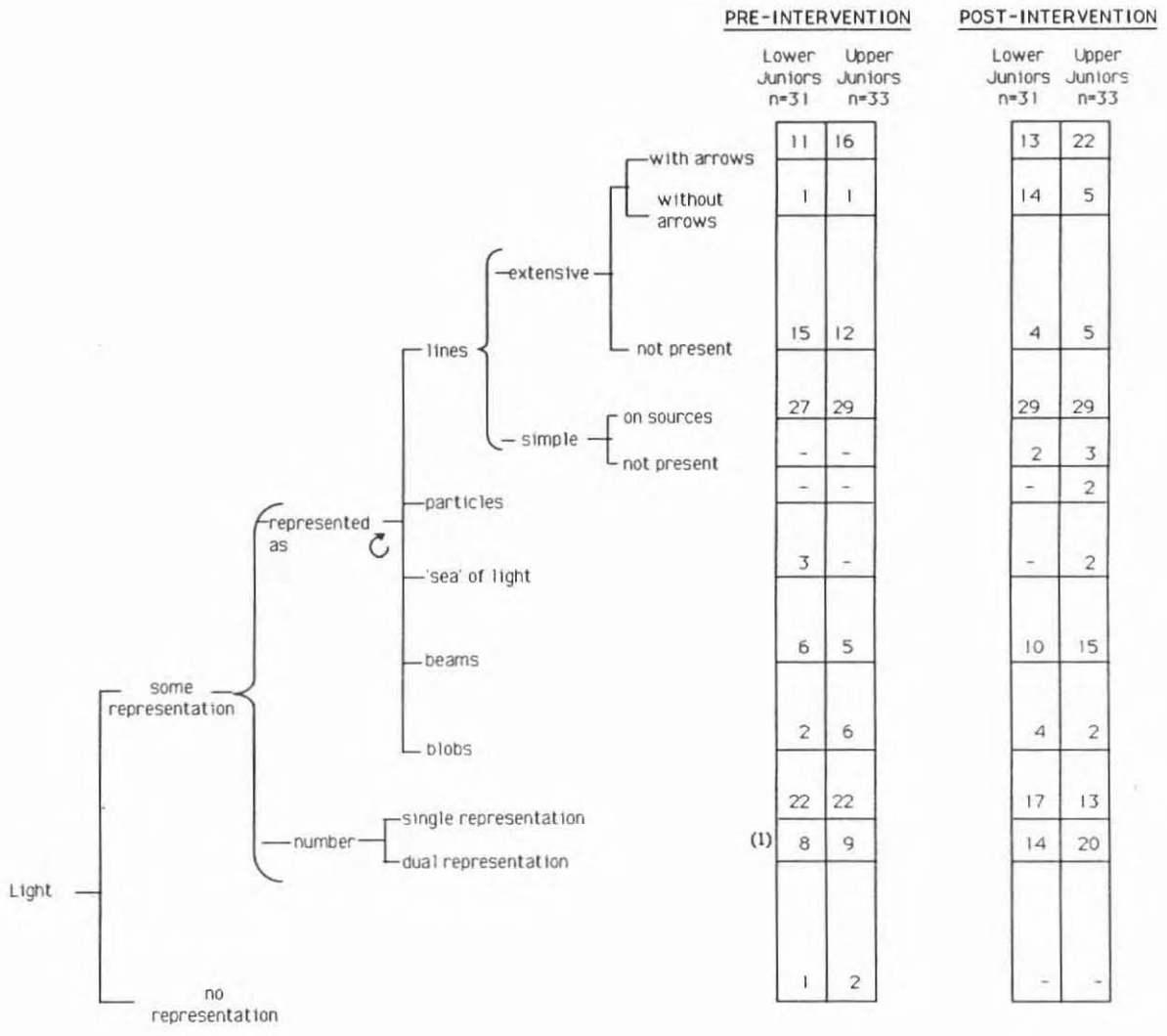
In this analysis the data about representations has been taken from drawings and explanations which show or discuss light alone. Representations of vision or links between the eye and object were considered indicative of some understanding of vision and not used for this analysis of children's representations of light.

Again the results obtained have been categorised using a network shown in Table 7.5 & 7.6. These summarise the main features of the representations employed by children. The dominant feature of children's work was the use of lines as a means of representing light from a relatively early age (Fig 6.20 & 6.22). And secondly, to incorporate arrows which showed a sense of direction. It was also noticeable that nearly all children's work included small, short lines around sources (Fig 6.2). The strength of this feature (87% minimum in any one sample) is perhaps surprising and it may be an *a priori* construct to developing a more sophisticated representation.

However, this was not the only representation found. Others were particles where the light was shown as string of small balls or a broken line; a 'sea of light' where the light was shown in shading across the whole drawing; beams where the light was indicated as a broad beam of light rather than a narrow line and 'blobs'. 'Blobs' was the term used by some of the children to describe a patch of light which they draw at the end of the torch or on a mirror or piece of paper.

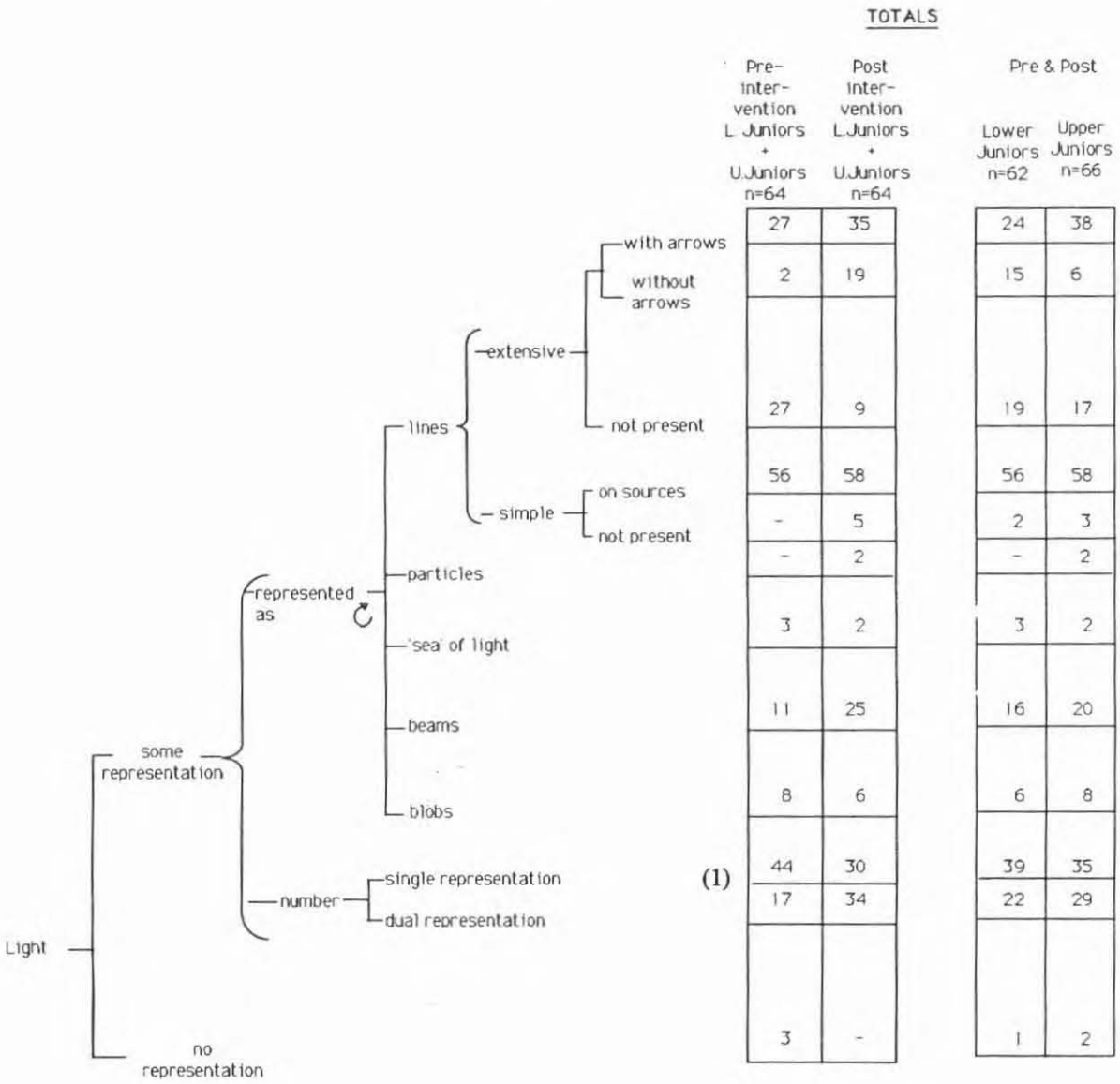
(contd overleaf)

Table 7.5. Network analysis of children's representations of light



1 These figures show the total No of representations. In this example 22 lower juniors use a single representation and 8 use a dual representation which makes a total of 38 representations. The nature of these representations is shown by the upper half of the network.

Table 7.6. Network analysis of children's representations of light. Data for Totals



· See the note on Table 7.5

The range of the representations used is surprising. Some representations were possibly rooted in observations of beams of light from torches and 'blobs' on paper. However, the observational evidence for light consisting of lines is relatively tenuous and based on limited observations. Little evidence was found here for the notion that humans and objects exist in a 'sea of light'. However, this may reflect a failure of the elicitation and a difficulty for children in representing such a concept.

The other feature of the children's work is the appearance of representations which are context dependent and vary with the task. Though the majority used a single representation, there were a number who would switch the representation from one question to the next. Time did not allow an investigation of whether those children who

showed a single representation were being consistent or whether the elicitation failed to evoke another representation. One interpretation is that many representations are observationally dependent and that the children just drew what they observe i.e beams with torches and lines with candles.

The figures are presented in a similar manner to tables 7.1 and 7.2. There are essentially three main features to the tables that should be noted. Firstly, the intervention has produced a significant increase in the number of children using lines as a representation for light.

Table 7.7. Total Number of Children Using Extensive Lines to Represent Light

	Pre-Intervention		*Post-Intervention*	
	Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
Extensive Lines	12	17	27	27
Percentage	(39)	(52)	(87)	(82)
Totals	29		54	

Table 7.7 shows the values obtained by adding the first two terminals on the network together. The result shows a significant change ($p<0.01$) in the number of children using lines to represent light for both groups and the totals. A closer examination of the network shows that the changes for lower juniors can be explained by a larger number who used lines showing no sense of direction. For upper juniors, the significant change is due to a larger number of children who showed representations of light with a sense of direction.

However, it is notable that the totals for lower juniors and upper juniors show a significant increase ($p<0.05$) in the number who used arrowed links anyway. If the ability to represent light in the form of a line is considered indicative of a more sophisticated model, an implication of this result is that children of age 9-11 are developing the ability to think with such models anyway. However, the increase in significance suggests that the intervention, with its emphasis on drawing and representing light, may have contributed to this development.

The second feature of the network was the increase in the number of upper juniors using beams as a means of representing light. All the other significant changes occurred for upper juniors and these are shown in Table 7.8.

Table 7.8. Statistical significance of changes for representations

	Lower Juniors	*Upper Juniors*	*Totals*
Representations as beams	-	$p<0.01$	-
Single Representations	-	$(p<0.05)$	-
Dual Representations	-	$p<0.01$	$p<0.05$

The increase in the number of children who used beams to represent light has no clear explanation other than that it may be based in more careful and thorough observation of car headlamps and torches. What the figures do suggest is that more children are using beams *and another* representation for light so that there is a decrease in the single representations and an increase in the dual representations which is the third feature of the networks. Possibly, this is indicative of a greater fluidity in children's understanding which although richer in its repertoire, is still very context-specific. Finally it is worth noting that very few children provide no representation of light in their responses.

Summary: *The evidence can be summarised as follows.*

a. *Nearly all children will represent light around a source with short lines.*

b. *The majority of upper junior children showed light using extensive lines. The representation of light as a ray or line was seen to increase between the ages of 7 and 11. Part of this development would appear to occur with age and some of the development could be explained as a consequence of the specific intervention activities.*

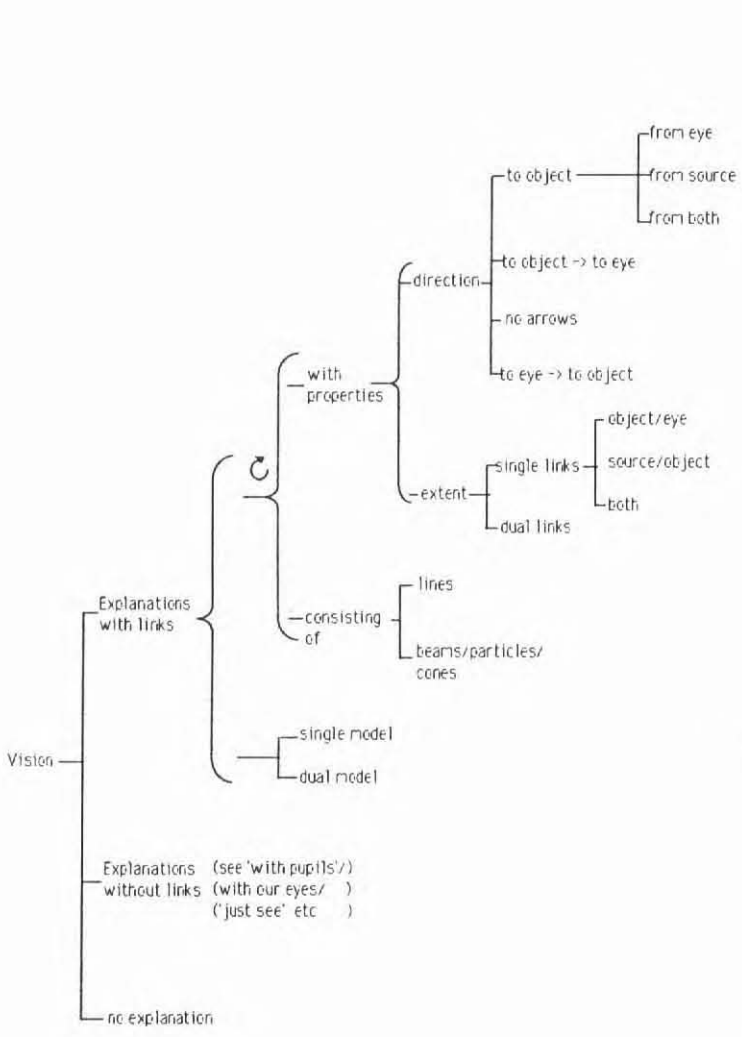
c. *Representations of light used by upper junior children become more varied and context dependent. Significantly more children provided responses that used more than one representation of light to answer similar questions after the intervention. Part of the increase could be explained by a significant change in the number that use beams to represent light.*

d. *Nearly all children provided some representation of light.*

7.1c Young children's Understanding of the Nature of Vision

Three topics in the elicitation materials addressed the nature of vision and the understanding shown by children. Pupils were asked (a) to show how they were able to see the light from a torch in a mirror, (b) to explain how they saw a book to a younger brother and (c), to add to a drawing to show how they saw a clock on the wall. These activities produced a wide range of responses which are summarised in Table 7.9 and 7.10 and the main features are discussed here.

Table 7.9. Network Analysis of children's responses to questions about the Nature of Seeing.

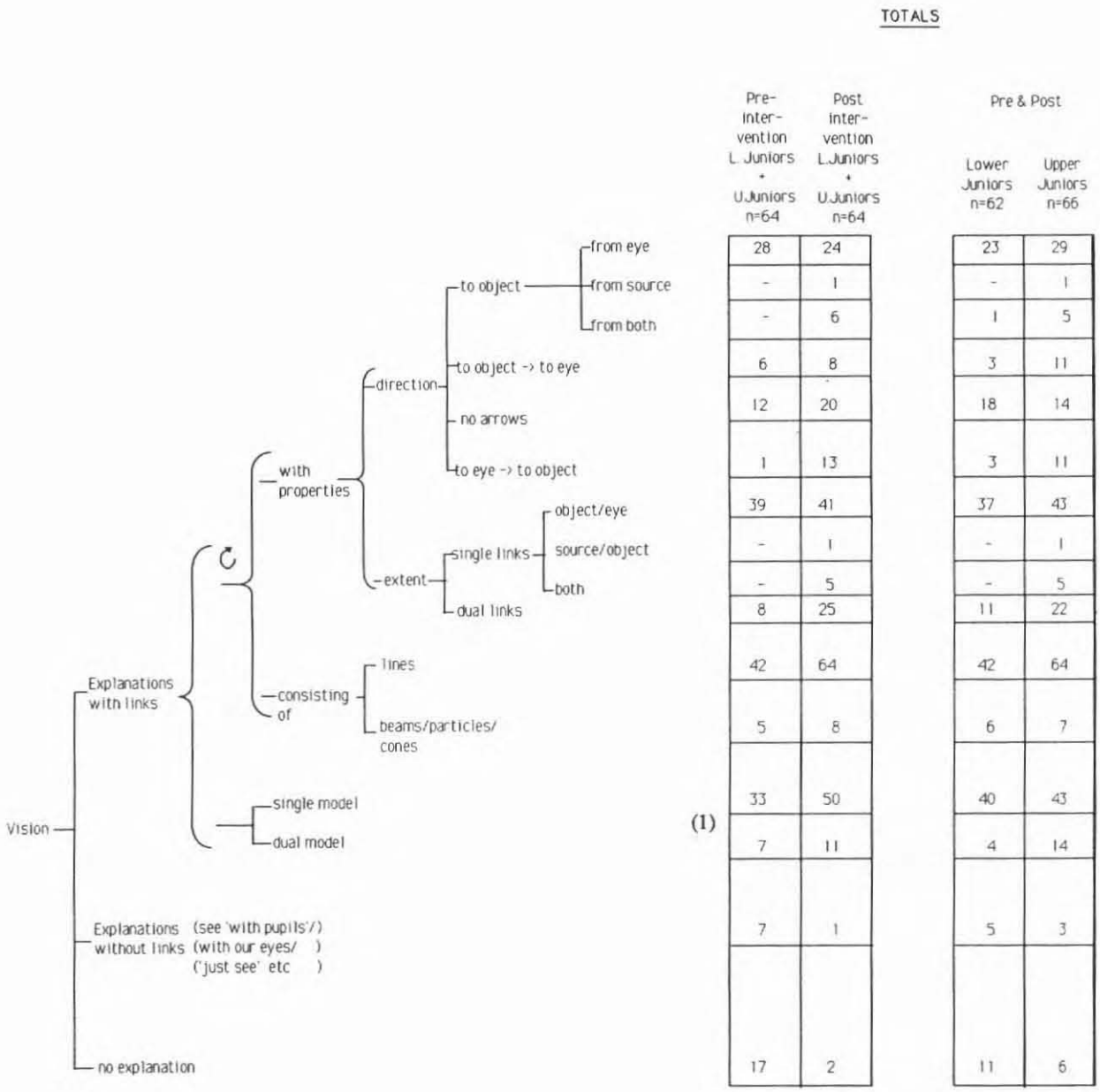


	PRE-INTERVENTION		POST INTERVENTION	
	Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
	12	16	11	13
	-	-	-	1
	-	-	1	5
	3	3	-	8
	5	7	13	7
	-	1	3	10
	14	25	23	18
	-	-	-	1
	-	-	-	5
	6	2	5	20
	18	24	24	40
	2	3	4	4
(1)	12	21	28	22
	4	3	-	11
	4	3	1	-
	11	6	2	-

Notes

1 The network is best understood by examining the figures for 'single' and 'dual' models. i.e for Lower juniors prior to the intervention, there were 12 single model responses (with links) and 4 dual model responses making a total of 20 responses in all. The upper half of the network shows what form these responses took.

Table 7.10. Network Analysis of Children's responses about Vision showing data for total figures.



1 See note 1 on Table 7.9

The data shows that children of all ages readily produced responses that used links between the eye and the object and that many incorporated the sense of direction. The number of such responses is shown in Table 7.11.

Table 7.11. Analysis of responses obtained which show links between *eye* and *object*

	Pre-Intervention		*Post-Intervention*	
	Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
No. of Responses showing link between Eye and Object.	20	27	28	44
No. of responses showing single links	14	25	23	24
Responses showing Dual Links	6	2	5	20

The data shows a significant increase in the number of both upper and lower juniors who show a link between eye and object. The other noticeable feature of table 7.11 is the decline in the number of responses from upper juniors to explain vision using single links between *the eye* and *object*. These responses dropped from 25 out of 27 to 24 out of 44 which is significant ($p < 0.01$). This was accompanied by a significant increase in responses from upper juniors which showed dual links to 20 out of 44 responses ($p < 0.01$).

Table 7.12 shows that for those that showed a link between eye and object, the majority of children at all ages incorporated a sense of direction into their response about vision. None of these changes are significant.

Table 7.12. Percentage of responses showing the sense of direction of vision.

	Pre-Intervention		*Post-Intervention*	
	Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
Arrowed (%) Link	75	69	54	84

Another noteworthy point is that there was a small minority of children in the lower juniors (15%) who are able to provide responses in terms of accepted scientific theories of vision by indicating that the light goes to the object and then to the eye. However, it would appear that such thinking was not robust as the post intervention data showed that

no lower junior children had this model. Lower juniors also showed a large minority (35%) of children who provided no explanation for vision.

One weakness of the network is a failure to show children who indicated in writing in one context that vision occurs 'with our eyes' or that we 'just see the book' in addition to providing a drawing as another response. The number of such responses was counted separately and shown in Table 7.13.

Table 7.13. Percentage of children providing additional written responses to explain vision.

	Pre-Intervention		*Post-Intervention*	
	Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
Written (%) response	29	24	55	24

The change for lower juniors was just significant ($p<0.05$) but there is no evidence to explain this change. The data indicates that there are a number of children who view vision in certain contexts as being essentially non-problematic. Seeing is just something which happens and you see with your eyes. However, the networks show that there is a very small number of children who use this response solely. For the lower juniors, there was also a minority who offered no meaningful response to explain vision.

An analysis of the responses which showed statistically significant changes is summarised in Table 7.14. In this network it is possible for a child to appear in any one of the upper terminals twice, depending upon the responses that they provide. The significance of changes has been evaluated by considering the change in the total number of responses of any one type in relation to the total number of responses. For instance the number of responses from upper juniors, which show vision in terms of a single link to object from the eye, decreases from 16 out of 27 responses to 13 out of 44 responses.

Table 7.14 shows that the majority of changes have occurred for the upper juniors. These can be summarised as a decrease in the number of children using responses which showed a link from the eye to the object; a decrease in single links; a decrease in responses without links and a decrease in responses which provided no explanation. This was coupled with an increase in the number that showed an explanation with dual links and used dual models to explain vision. However, the latter is not accounted for by an increase in the number of children using scientific models of vision but by a growth in the number of children using explanations that show the light going to the eye and then to the object. This result suggests that more children were aware that 'light is necessary for vision' and 'eyes are needed to see' and were attempting to show both features.

Table 7.14: Statistical significance of changes in children's ideas about vision.

	Significant change in the elicitation after the intervention by:			*Overall differences between Lower Juniors & Upper Juniors*
	Lower Juniors	Upper Juniors	Total	
light shown to object from eye	-	(p<0.01)[1]	(p<0.01)	-
no arrows shown	-	-	-	(p<0.05)
light shown to eye to object	-	p<0.05	p<0.01	-
single links shown object-eye	-	(p<0.01)	(p<0.01	-
dual links	-	p<0.01	p<0.05	-
single models of vision	p<0.01	-	p<0.01	-
dual models of vision	-	p<0.05	-	p<0.05
Explan-ations without links	-	(p<0.05)	(p<0.05)	-
no explan-ation	(p<0.05)	(p<0.05)	(p<0.01)	-

[1] Changes representing decreases are shown in brackets

Part of the increase in the use of dual models can be explained by the change observed between lower juniors and upper juniors which is significant. The only other significant changes between the lower junior cohort and the upper junior cohort was a reduction in

the number of children who showed no arrows on their drawings. This suggests that part of the observed change in the use of dual models can explained by development which occurs with age.

The increase in dual models would support the hypothesis that children's thinking is context specific and that their ideas are fluid and pliant which has been mentioned elsewhere.

The lower junior children show very few changes. The principal change is an increase in the number of children who show a single representation. This could be explained by the significant decrease in the number of children who provide no meaningful response which suggests that these children are now showing at least one explanation for vision of greater complexity.

Finally, the observed changes are somewhat surprising as the intervention avoided directly addressing this idea of vision. It is possible that the children placed a different emphasis on the activities to that intended. Explanations about the phenomena may be of an egocentric nature which places an emphasis on the function of sight. However, there is no evidence which provides more insight.

In summary, it is clear that the intervention has had more effect on children's development for the upper juniors than lower juniors. This is a similar conclusion to that drawn from looking at the representations for light. The inference is that such work has possibly more value if tackled at a later stage in a junior child's development.

Summary: *The evidence can be summarised as follows.*

a. *More than half the children provide responses which indicate a link between eye and object and the majority of these responses incorporate a sense of direction.*

b. *A sizeable proportion of lower junior children (35%) provide responses which show no explanation of vision and indicate that the idea is non-problematic for them.*

c. *The major effect of the intervention work was on upper junior children who provided more responses which showed increased use of dual links i.e eye-object and object-source. This was accompanied by an increase in the number of dual models reflecting an increase in the context dependence of responses. The implication is that such work is more appropriate to children in the 9-11 age range.*

d. *The only significant effect of the intervention for lower junior children was to increase the number of responses showing single links between object and eye and decrease those showing responses which provided no explanation.*

7.1d Context dependence of responses.

For the purpose of this study, we have used the notion of 'context dependence' to describe the responses of children which show different representations of light or different mechanisms of vision *within the same elicitation*. An example of such a response is shown in Fig 6.26(a) & (b). Throughout the study, this was one of the most noticeable features about the responses obtained from children. Table 7.15 summarises the figures from the network and shows the percentage of children showing such responses.

Table 7.15: Percentage of children providing responses which show more than one model and which are inconsistent.

	Pre-Intervention		*Post-Intervention*	
	Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
For representations of light	25%	27%	45%	60%
For explanations of vision	13%	9%	0%	33%

The changes for upper juniors were significant and showed an increase in the use of context dependent models. Ideally science education should try and facilitate the construction of robust understandings that are generalisable. This was clearly not the case here and it is possible that such a period may be the precursor of the development of ideas which are more permanent and closer to a scientific understanding.

There are various alternative explanations for such behaviour. A Piagetian perspective would be that all these children were exhibiting early or late concrete thinking which is essentially tied to the observable features of such phenomena. Consequently, the children do not perceive any inconsistency in the different representations which would be apparent to a formal thinker. For them, there simply was no conflict.

However, it may simply be a period of trying a new idea whilst clinging to an old interpretation - indeed, perhaps an essential stage in the development of children's thinking. What it indicates is an addition to the child's ideas for making sense of the world. The implications for teaching are that children should have the opportunity to test their thinking by trying such ideas. Only this would provide the necessary experience to develop their understanding.

Summary: *a.* *Many children's responses to questions about their understanding of light showed different answers in different contexts.*