An investigation into some Key Stage 2 children's learning of foundation concepts associated with geared mechanisms

RESEARCH

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Abstract

This paper describes a small scale research project conducted with six Year 6 (11 year old) pupils into the development of their understanding of key concepts associated with geared mechanisms through practical activities with construction kits.

Although the children were able to construct models following instructions and explain the function of the mechanisms, they were unable to apply this knowledge to a problem-solving situation. Timely teacher intervention was required to enable them to progress through the development and application of anchoring conceptions.

This piece of research probes the extent to which the children develop understanding of geared mechanisms with minimal teacher intervention. It examines the forms of language which children develop to explain the phenomena they observe and to put forward their own theories. It speculates on the implications this may have for children's conceptualisation and the organisational strategies teachers might need to employ to maximise learning. Findings suggest that the level of involvement in a task and the extent of a child's concomitant learning may not be readily judged from observable features such as verbal or active participation. "Engagement" and interest would appear to be at least as important as "word work" or practical activity.

Rationale

The reasoning behind conducting this investigation has been a desire to find out more about the problems children encounter when attempting to gain an understanding of the principles of geared mechanisms. National Curriculum guidance in England and Wales suggests that children at Key Stage 2 (7-11 years) should use:

> "...construction kits to explore ways of using gears to speed things up and slow them down" (SCAA, 1995)

Informal observations and discussions with primary teachers regarding the use of Lego construction kits with Key Stage 2 children suggest four strategies for their deployment:

1. Children "free play" with the kits to construct items of their own choosing

2. Children follow printed instruction cards and make replicas of the models depicted on them

3. Children modify ("kit-bash") the models suggested on the manufacturers' published material

4. Children set out to make particular models to, for example, illustrate an aspect of a class topic they are studying.

The aim of this study has been to attempt to gain an insight into the strategies some children employ in learning about geared mechanisms by close observation and interaction, and to speculate about the cognitive structures they are using. The methodology employed in gathering data is principally ethnographic (through videotaped observation and semi-structured interviews) but some quantitative data have been accumulated through analysis of the video recordings by logging the children's utterances and timing each child's physical contact with the equipment.

The issue

Many writers point to the links between science education and technology education (e.g. Layton 1993a, Layton 1993b, Jenkins, 1993). It has been argued (e.g. Layton, 1993a) that a principal difference between the value of knowledge in science education and technology education is that science is more concerned with knowing *that*, whereas technology is more to do with knowing *how*. The application of scientific knowledge and understanding to the solution of a practical problem is the hallmark of technology education and the driving force behind this investigation.

Several studies highlight problems children have with developing scientific concepts. Most notably Driver *et al* (1985) catalogue many of the scientific misconceptions children (and adults) hold, and the reluctance they have to abandon their intuitively derived notions. Driver (1993) draws upon evidence which suggests that

the prior knowledge and experience which children bring to science classes

> "may differ substantially from the ideas to be taught, that these conceptions influence further learning ..." [Driver, 1993, p 112-3]

Clement *et al* (1989) strike an optimistic note by positing that not all preconceptions are necessarily misconceptions, and that some may form "anchoring conceptions" on which to build understanding. One feature of their research was the remarkable "uniformity in results" [ibid., p. 557] of the subjects they studied, suggesting that many potential anchoring pre-conceptions are consistently and almost universally held (e.g. that forces are only associated with motion).

This investigation was aimed at discovering the extent to which children apply intuitive preconceptions or the ideas they develop through preliminary contact with geared mechanisms, and whether these ideas might prove useful building blocks for conceptualisation.

Underpinning Driver's and Clement's work is a constructivist view of learning, based on the notion that, like scientists, children construct understanding by continually testing internal models of the world with reality. Sutton (1992), takes this further by insisting that science teaching is a process of ....

> "inducting someone into new ways of seeing and new ways of talking" [Sutton, 1992, p. 47]

... by using language and experience to "recreate" implicit ideas. A focal point of his thesis is what he sees as the overriding and undervalued importance of language in the science learning process; more specifically that ...

> "the total time devoted to Word Work ... should exceed that spent on Bench Work." [ibid., p. 72]

Vygotsky's (1936) work on the relationship between language and learning is extensive and influential but, for the purposes of this study, his theories associated with scientific concepts and what he terms "the zone of proximal development" are particularly relevant.

For Vygotsky, everyday (spontaneous) concepts begin with experience, whereas scientific concepts begin with verbal definitions (see Vygotsky, 1936, p. 108-9). He argues that scientific concepts tend to be formed under adult influence – through language and instruction – but children differ in their capacity to learn with assistance. The extent of this "excess" capacity for learning Vygotsky terms the "zone of proximal development"; the greater the zone, the more the child is capable of learning.

There is a tendency for primary school technology to focus on practical work, due in part to the National Curriculum's emphasis on designing and making. Most primary teachers recognise the importance of practical activity to learning, but is practical activity alone sufficient to develop understanding? Children are unlikely to experience geared mechanisms in any other area of the curriculum. If the constraints of time and resources (and probably teacher knowledge) restrict the type of contact children have with construction kits to activities following printed instructions or to open-ended problem solving tasks with minimal teacher intervention (as detailed above), then how might these be used more effectively to develop children's understanding?

Finally, the issue of gender has been discussed at great length in relation to practical technology activities (e.g. Brown, 1991; Wood and Newton, 1992; Sullvarna-Hall, 1993) and more particularly children's use of construction kits. Claire (1992) found for example that girls needed more time, particularly at the planning stages, to develop their ideas and experiment with kits before tackling a problem. Girls, she found, were more systematic in their approach and more cooperative, whereas boys tended to be more competitive and haphazard. Although gender differences are not a

primary focus of this piece of research, the extent to which they might affect the way different children approach a task might have implications for the ways in which activities with mechanisms are organised.

This piece of research probes the extent to which the children might develop understanding with the minimum of teacher intervention. It also examines the forms of language which the children themselves develop to explain the phenomena they observed and to put forward their own theories. It speculates on the implications this may have for children's conceptualisation and the organisational strategies teachers might need to employ to maximise learning.

The approach

The study was conducted with six Year 6 children, over a three-week period and involved a set of related activities centred on Lego Technic.

The children were selected from the final class of a primary school, the only criteria for selection being there should be three boys and three girls. The teacher decided to choose six children who were "practical".

The activities were conducted in a spare classroom and all were videotaped. The camera was mounted on a tripod in the corner of the room and provided with a wide-angle lens, a zoom microphone or a remote microphone positioned in the centre of the table to pick up children's verbal interactions. Occasionally the camera was moved to ensure that the focus of the activity remained within the field of view but apart from this, the camera remained unobtrusively in the background. The use of videotape allowed subsequent detailed quantitative and qualitative analysis of the children's spoken comments and their actions.

The first four activities were aimed at providing some background information about the children's "Lego capability" and some insight into their understanding of mechanisms. They also deliberately resembled the types of classroom activities with construction kits which teachers currently use at Key Stage 2. These activities also provided the children with an opportunity to become familiar with me as teacher/researcher, the Lego kits, the camera and to establish some foundation awareness of geared mechanisms (i.e. to form some intuitive/spontaneous conceptions). These preliminary activities spanned two weeks and were conducted in four half-day sessions with all six children. They were videotaped for later analysis.

The four preliminary activities were:

1. An introductory session in which the children worked individually making identical LegoLand vehicles following the printed instructions provided with the kits (Structured practical work)

2. An open-ended activity in which the children were asked to work individually making "a machine" powered by a Lego motor. (Semi-structured practical work)

3. A "sharing" session in which each child explained the workings of their model to the others. (Word work)

4. A directed activity in which the children, working in pairs, were given previously constructed "Black Box" mechanisms and were required to study the relationship between the input and output motions and predict what mechanism might be hidden in each box. They were required to justify their predictions to each other by sketching and discussion (Word work).

The fifth activity was the most significant part of the investigation and, as a consequence, yielded the most data. The children were required to work in pairs to build a vehicle which would move the least distance in one minute, powered by a Lego motor. The children were paired to encourage verbal interaction and these conversations were videotaped and transcribed. The amount of time each child spent in purposeful construction was logged, as was the quantity and content of the teacher/researcher's interventions.

The final activity took the form of a semi-structured interview with each child individually. The interviews were transcribed to yield qualitative information about the children's understanding of geared mechanisms and triangulate findings from the previous practical activity.

In addition to the above data, further background information was derived from the class teacher as to the children's general aptitudes for, and attitudes to, practical work and each other in the classroom.

The results

For convenience the children will be referred to as follows:

AB – Child A (Boy) CG – Child C (Girl)
CB – Child C (Boy) EG – Child E (Girl)
LB – Child L (Boy) MG – Child M (Girl)
and the teacher/researcher, as T.

Activity 1 – LegoLand vehicle construction

The children set about this activity with vigour and enthusiasm (the kits were brand new and unopened). Some variation was evident in their approaches, but all children were sufficiently familiar with Lego to complete the models unaided (apart from CG who requested a little assistance when MG had finished her model) (see table 1).

Activity 2 – Make a model with a motor

Initially they were given no guidance, but after 20 minutes of fairly fruitless activity Lego instruction sheets were provided for reference. Four went on to follow printed plans, while two made models of their own designs with intensive teacher "hands-on" input on the construction of the mechanisms (see table 2).

Table 1

Child	Time taken (Min:sec)	Comments
AB	6:18	Confident and accurate construction with minimal errors
CB	8:33	Steady construction, no errors
LB	7:55	Haphazard approach, many errors
CG	9:00	Careful construction, some major errors (Sought guidance from MG)
EG	7:48	Careful construction, minimal errors (Worked with MG)
MG	7:45	Careful construction, minimal errors (Worked with EG)

Table 2

Child	Model	Type of support	Comments
AB	Vehicle with compound gear train drive	Teacher	Needed considerable help with the geared mechanism
CB	Vehicle with worm spur gear drive	Published card	Worked mostly unaided once he had the card
LB	Vehicle with chain transmission	Teacher	Needed considerable help with constructing the geared drive mechanism
CG	Vehicle with twin worm drive	Published card	Needed occasional guidance on interpreting the diagrams on the card
EG	Vehicle with pulley and spur gear drive	Published card	Worked mostly unaided
MG	Roundabout with worm drive	Published card	Worked mostly unaided

Activity 3 – Explanation of the workings of their models

The children were asked to explain clearly how the gearing systems worked to indicate the extent of their working knowledge of gears. All children gave plausible explanations about the transference of motion from one part of the mechanism to the other. All agreed that the worm gear was the most effective way of slowing down a motor and all appeared to appreciate the relationship between the size of interconnected spur gears or pulleys and speed reduction (small to large).

Activity 4 – Black box mechanisms

The children worked in pairs, discussing and sketching the mechanisms inside each box. Although only "correct" responses were recorded, some of the "incorrect" responses were plausible mechanical solutions to the problem (see table 3).

Activities 5 and 6 – Slow vehicle challenge and post-task interviews

The children paired themselves into a girl-pair (MG and EG), a boy-pair (AB and LB) and a mixed-gender pair (CB and CG). There was a marked contrast in the ways the pairs went about the activities, as can be seen from both the qualitative and quantitative data.

In quantitative terms the contribution made by each individual, including the teacher (T) to the problem solving construction task is shown in table 4.

It would appear that the workload was shared fairly evenly in the girls' pair (EG and MG), with the teacher contributing around a tenth of the input.

The teacher's contribution to the boys' pair (AB and LB) was similarly around a tenth,

Table 3

Pair	No. of mechanisms analysed successfully	Comments
AB & LB	2 / 5	Many disagreements and a tendency to over complicate the solutions (e.g. multiple gears to achieve the same result as a universal joint). Tried to "cheat" on at least two occasions.
CB & CG	4 / 6	CB took most of the initiative, but would always ask CG for her opinion. Very meticulous in their explanations and approach.
EG & MG	5 / 7	Very quick at making their decisions, very few disagreements. Very accurate predictions – even to the relative size of the meshed gears or interconnected pulleys.

Table 4

	Verbal contribution (No. of Statements)		Physical contribution (Hands-on kit) (Secs)		Overall contribution
Name	**No**	**%**	**Secs**	**%**	**%**
EG	158	45	1731	39	42
MG	140	40	2420	54	47
T	52	15	324	7	11
AB	219	46	3275	66	56
LB	204	43	1213	24	33.5
T	49	11	496	10	10.5
CB	72	40	1835	68	54
CG	10	6	187	7	6.5
T	95	54	690	25	39.5

though AB's contribution, particularly with regard to hands-on construction, was significantly greater.

The totals and distribution of verbal interchanges and hands-on work was markedly different for the mixed pair, however. The girl (CG) tended to take an acquiescent back seat, contributing few spoken comments and spending a total of little more than three minutes in actual physical contact with the equipment out of a total construction time of approximately 65 minutes. The teacher's contribution, particularly the verbal comments, was greater in proportion and in quantity (almost twice the number than with each of the other pairs).

At first glance, based on these quantitative data, it would appear that in this activity:

- the girls' pair were more equitable in the allocation of the task and discussion – and thereby possibly, the thinking
- the boys' pair shared the talking and hence possibly the thinking, though one was slightly more involved in the making
- in the mixed pair, the boy took the initiative and the girl was a passive onlooker.

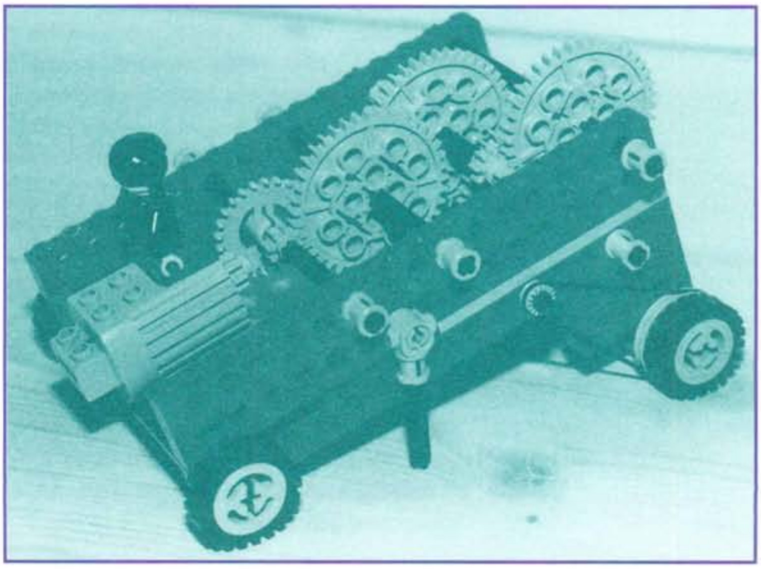
How does this relate to the qualitative data?

MG and EG (Girl pair)
With the girl pair, the qualitative data tends to support the quantitative data regarding the share of thinking in the task. The girls were far more willing than any of the other pairs to listen to, and try out, each others' suggestions and put forward reasoned challenges, especially in the early stages of the activity. For example:

9:07 EG If we stick a cog ... on there (*does so*) ... like that (*MG watches*)
MG Stick a small one on there .... and make it go to a bigger one
EG Big one? Let's see ... (*searches in box)* ... where's? (*MG searches other box*)
EG They're all different ... (*Connects motor*) ... There, see! (*MG watching*)
MG Wait! If we stick a small one on here (*takes model*), cos it's easiest ... two small ones and a big one ... cos that's ...
EG OK... how are we going to do that? ... Like that?
MG Yeh
EG How?
MG I dunno ...
EG Oh ... I know (*takes model*)
MG Use one of these? (*takes part from box*)
EG No ... get one of these (*takes part from box*) ... a little ... we put that on there ... (*does so*)
MG What are we going to stick it under?
10:21 EG That board ... on there.

There are several instances such as this where the initiative (and presumably the thinking) and the action are shared evenly. The half completed model was passed back and forth between the girls on a regular basis and at times it was placed on the table between them while they discussed it.

After about 30 minutes the teacher/ researcher intervened as they were not making progress with the construction of a workable geared mechanism and provided them with verbal and practical information about the key concept for making a



The girl pair's model. Note the crown wheel taking the drive from the motor to the first shaft which caused consternation during the construction. The vertical rod was used for accurately measuring the distance travelled in one minute

compound gear train (i.e. putting two gears on one axle). From this point onwards MG appeared to take more of the initiative, having to correct some of EG's ideas. In this interchange for example, EG is convinced (erroneously) that two crown wheels on the same shaft either side of a spur gear will transfer the motion – MG is equally convinced (correctly) that this will lock the mechanism.

33:33		(*MG assisting EG as she adds another crown wheel to the first drive shaft*)
	EG	We need to put them quite close (*Pushes both crown wheels together, so one is meshed each side of the motor pinion*). That's it! Ooops! Let's try that ... (*Picks up battery pack*)
	MG	Wait, let's move this one up (*Slides one crown wheel along shaft away from pinion – action also unmeshes the other crown wheel*) (*EG turns on motor, sound of grating gears*)
	MG}	(*together*) It's not touching
	EG}	(*together*) ... we should have both of them touching (*starts to move the crown wheels back together*)
	MG	No, don't!
	EG	You've got to!
	MG	You don't ... it won't work (*EG has moved them and turns on motor —the mechanism is locked – no movement*)
	MG	See!
	EG	Oh yeh!
	MG	You just want that one nearer. (*She slides one crown wheel along, the whole shaft moves with it*)
	EG	We need things [bushes] on the end [of the shaft] (*They both struggle with the Lego*)
34:29	MG	(*To teacher*) We've got ideas, it's just the Lego won't work!

However, despite a few operational difficulties with the kit and some initial confused thinking, the post-activity interview revealed EG had eventually developed quite a sophisticated grasp of the workings of a compound gear train:

Teacher	Can you explain to me how you can slow a motor down? How it actually ...
EG	By having big to big to big to big ... and that gradually slows it down.
Teacher	OK ... big to big to big doesn't really tell me how it's actually working. Can you explain to me what actually goes on?
EG	Well, you have on one ... like ... stick (*axle*) you have a big cog and a little cog and the big cog is turned by a motor and the little cog is turned by the big cog really because that turns round this stick. (*she demonstrates with gears on the table*)
Teacher	Right...
EG	And so, (*demonstrating*) that is joined to a big cog, which turns another little cog, which turns a big cog, which turns a little cog, which turns a big cog, which turns a ...
Teacher	Right OK

EG went on to give an acceptable, unprompted account of gear ratio (using the term "span").

MG's explanation was equally well detailed and suggested her grasp of the gearing principle was also well founded, as evidenced by her domination of the provision of ideas and greater proportion of hands-on work in the latter part of the fifth activity.

AB and LB (Boy Pair)

The quantitative data for this pair seems to indicate that while AB did more of the construction, they shared the discussion – and hence the thinking – reasonably fairly. A qualitative assessment of the pair's utterances and the boys' physical activity reveals a quite different picture, however.

LB's statements were mostly concerned with the chassis of the vehicle, or the construction of a chain linkage transmission which was superfluous to the assigned task of creating a geared speed reduction system. Whenever he did contribute to the

construction of the gearing system, it was mostly in response to AB's initiative:

48:20 (*AB sitting, experimenting with motor and gears – LB at boxes, selecting parts and assembling a chassis*)

LB How many gears do you want on it? (*Continues sorting through boxes*) They go down each side, don't they? (*No response from AB*) Cos if we're going to have ten, we need five on each side.

AB Yeh, but we need to fix this on, don't we, otherwise it'll .... sort of like ... be like that ... (*Holds up motor assembly*)

LB Oh, I know ... yeh. (*Moves to AB*) I know, yeh! ... ummmmm (*Takes motor assembly – turns it over, scrutinises it*) Put it ... ummmm ... yeh ... there ... (*inaudible*)

AB (*Inspirationally*) Or... a better idea would be cog-wheels ... They would make it even slower ... (*Tries to take assembly back*)

LB Cog wheels? (*Holds on to assembly*)

AB On there (*pointing*) ... Or ... (*Rubs face with hand*) ... (*inaudible*) (*4 second pause*)

49:19 LB You'd have to have chain on it ... We could put these tiny wheels on ... (*Goes to boxes , AB follows*)

LB's obsession with chain-drive may have stemmed from Activity 2 where his original model successfully employed it, though the gearbox was largely built by the teacher. As the activity progressed, AB took responsibility for the gearbox, and LB contributed the chassis and chain drive, then sat and became a passive observer – though he kept up a constant commentary (sometimes inaudible) which prompted the only negative affective comments from the normally even-tempered AB e.g.:

1:00:55 AB Shut up!

The post-activity interview revealed, as expected, a well-developed appreciation of geared mechanisms by AB:

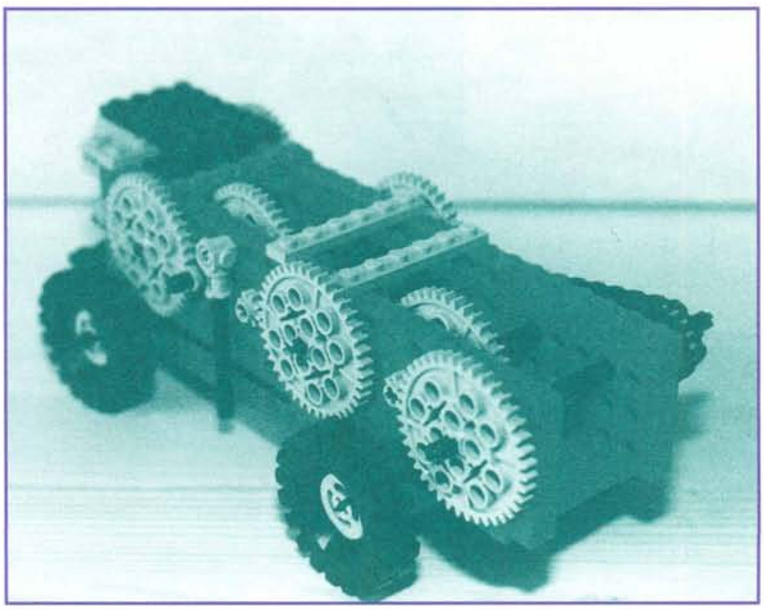
AB Well, you get a small cog .....
Teacher Yeh?
AB Then, if it's connected to a bigger cog ... it's ... that's going round a lot faster ... that slows it down ... because one of these [*small gears*] goes round about 60 times when one of these [*large gears*] turns.

AB then went on to clearly describe the construction of a compound gear train, and elaborated on his description by calculating the speed-reduction in a three-stage repeated 10:1 train.

Whilst LB had a good understanding of the small:large relationship:

LB You put a smaller one [*gear*] on the motor, then it has to turn round lots of times to make that [*large gear*] turn round once.

He had difficulty explaining the principles of a compound gear train. He also applied, what seemed to be his anchoring conception of small:large inappropriately to explain the workings of a worm gear:

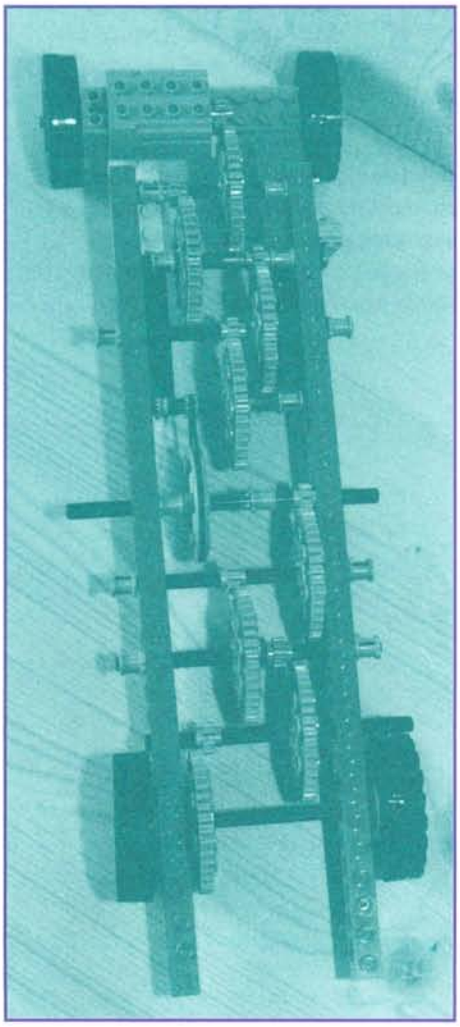


The boy-pair's model. Note LB's chain drive on the further side of the vehicle

Teacher	Which bit on here [*an example mechanism*] ... which bit of the mechanism, do you think, slows the speed down the greatest?
LB	Errr.... the worm gear.
Teacher	The worm gear ... why's that?
LB	Because ... errrr ... because ... it turns round on that axle ... errr ... because it's thinner, so it turns round loads and loads of times.

The geared mechanism was constructed principally by AB though LB occasionally did try to contribute. LB's subservience to AB and his obsession with the chain drive and the structure of the chassis gave the appearance of involvement with the task, but succeeded in detaching him from the most significant aspect of the problem – constructing the gearing system.

The mixed pair's model. This was later extended by CB to add a further three stages. The application of "small to large" and "two gears on one axle" can be seen early in this photo



CB and CG (Mixed pair)

So little verbal interaction took place with this pair, and that which did was mostly through the teacher, it is difficult to make an analysis of the talking and thinking underlying their approach to the problem. There were occasions when CB passed the model over to CG and, without any comment, CG took up the next stage of the construction, then passed it back. It was apparent that CG's engagement was continuous and quite deep, albeit mostly vicarious.

As CB dominated the construction, I was very interested in CG's understanding of the mechanical principles. This was revealed in the interview. Her appreciation of the small:large relationship was well founded:

CG	It [*the large gear*] only turns a tiny bit when the little one turns right round, which makes it go slower.

and she went on to give a lucid account of the workings of a compound gear train:

CG	Well, that [*small gear*] spins round, and that turns that one [*large gear*] which slows it down ... and that one [*pointing to the next stage*] slows it down even more ... well it slows it down the same amount as that one really ... and every time it goes round to the big one [*gear*] it slows down some more. So each time it's slower than it was before.

When asked why she hadn't participated in the construction, despite saying she enjoyed making things, she explained:

CG	I like watching and learning better, sometimes.

I had an opportunity to work with CG again after the interview when I asked her to construct a gear train. She did so successfully in under 15 minutes. Non-participation on a verbal or practical level did not, in this case, indicate a lack of understanding.

CB's account of gear ratios and the compound gear train was equally well detailed. Interestingly, after the "trials" in which the distances the children's models travelled in one minute were measured, CB went on to extend their model to incorporate another three stages of speed reduction when he discovered their vehicle was not the slowest. CB's final model moved 2 millimetres in a minute!

Discussion

Despite obvious flaws in the data gathering with such a small sample, there are a few tentative conclusions which can be drawn from this study:

All the children experienced difficulty in meeting the challenge set in the fifth activity. Despite carrying out the preliminary activities in which they were able to accurately describe the transmission of motion in geared systems and being shown – either by the teacher or through following printed instructions – how to gear down a motor with a worm gear or a compound gear train, they all failed to grasp the mechanical principles sufficiently to go on and apply this working knowledge to the construction a functioning mechanism without assistance.

This would suggest that the practice of giving children a kit and a set of instructions (as in Activity 2) is not an efficient way of encouraging learning. What is required is "engagement" with a task which focuses attention on the mechanical purpose of the mechanism – in this case to reduce the speed of a motor. It would appear that all the children spontaneously assimilated the notion of "*small to large*" gear relationships leading to speed reduction. This seemed to be an "anchoring conception" for them derived from their initial experiences with the kits. This concept appeared however, to dominate their thinking in trying to solve the speed reduction problem. Interestingly, despite agreement in Activity 3 that worm gears were the most effective method of geared speed reduction even those who had used worm gears in Activity 2 did not attempt to employ them in Activity 5. They all opted for spur gears and reached a stage where they could only think linearly, putting only one gear on each axle meshed with another gear on the next axle and so on. In all cases they kept trying to make the next gear larger, until they ran out of sizes. They did not consider having two gears of different sizes on the same axle even though many had previously done so in Activity 2. Until their attention was drawn to this key concept, they were unable to progress.

It seems that teacher intervention can be helpful in focusing attention and developing thinking. To expect children to make intuitive leaps unaided – particularly in conceptual areas which tax the intellect and practical capabilities of some adults seems a great deal to expect. In all three cases the intervention was required between 20 and 40 minutes into the activity. The children needed time to attempt the problem and realise they had insufficient knowledge and understanding to solve it.

With each group the same four level approach to intervention was adopted:

1. What appears to be the problem (with the gearing system)? Can you explain it to me?

2. How have you tried to solve the problem of gradually slowing down the speed of the motor?

3. Have you thought of putting two gears on the same axle?

4. Here, let me show you.

With the boy-pair, only level 3 was required. With each of the other two pairs, I had to resort to level 4. Claire (1992), suggests a supportive environment in which girls are given space and encouragement will help "empower" them with constructional activities normally seen as boys' work. The results of this investigation tends to lend weight to this view.

Vygotsky (op cit.) suggests that the acquisition of scientific notions requires adult language input. Not only was this apparent in this study, but the needs-related practical context in which the words

made sense was also a necessary precondition. It would seem that the provision of suitable practical experience in which attention is focused on a key issue may assist in the extension of Vygotsky's zone of proximal development. Whereas CG was able to assimilate the concept of "two gears on one axle" through vicarious involvement, LB's zone of proximal development did not encompass the problem of gearing down the motor, due in part to his obsession with constructing the chain drive. The locus of a child's attention is clearly an important factor in maximising the effect of a teacher's intervention.

Doise and Mugny (1984) have shown that children working in pairs and groups produce more effective solutions to problems than those working individually. This was very apparent with the girl-pair, in which MG was able to challenge and confront some of EG's partial conceptions. In the mixed pair, CG was able to develop her understanding by closely observing CB's progress. The boy-pair were less successful in that, although they were ostensibly working as a pair, LB effectively divided the problem into two discrete sub-tasks – the speed-reduction mechanism and the chassis / chain drive. To further develop Sutton's (op cit.) premise that "Word Work" is more important than "Bench Work", this study would suggest that "Engagement" with the task in hand is at least as important as either.

The use of technical vocabulary became an issue as the investigation progressed. At all times, I used correct terminology in my discussions with the children. I did not however, insist upon the children using correct technical terms as I was interested in hearing their own expressions and explanations to gain some insight into their mental models. It was interesting to note the reluctance or inability of the children to use the technical vocabulary in discussions. Axles were variously called "*stick-things*" (EG), "*spars*" (MG), "*that bit there*" (CG) and "*Little things – what's it called?*" (AB), gear-teeth were referred to as "*grooves*" (CB), "*ridges*" (LB), "*little slots*" (CG), "*little spike things*" (EG) and "*teeth*" (MG) – and yet this did not necessarily diminish the children's practical capabilities or willingness to explain their understanding.

The Design and Technology National Curriculum Programmes of Study for England and Wales requires the appropriate use of technical terminology at both Key Stage 1 and Key Stage 2 (see DFE, 1995). My concern is that insistence on the correct use of vocabulary does not automatically imply understanding. Whilst technical vocabulary may assist in communication, it should not be assumed it is a prerequisite or a necessary medium for the development of understanding.

Finally, despite the small scale nature of this study, it does lend some weight to previous findings about gender differences in practical activities. The girl pair (EG and MG) did work more cooperatively than the all-boy pair (LB and AB) and the mixed pair (CB and CG). Whereas all the girls furthered their understanding of the two key concepts (small to large, and two gears on one axle), one of the boys (in the boy-pair) did not engage sufficiently with the task on which his partner was working to master the latter concept.

It would be unwise, if not reckless, to generalise from these findings that boy-girl pairs are equally successful at problem solving in design and technology as girl-pairs. As Wood and Newton (1992) point out, there are many design and technology activities in which one gender will be likely to have social or prior experiential advantage over the other (e.g. girls with textiles, boys with construction kits). CG could not explain why she let CB dominate the construction – but the unacknowledged pressure of gender role-typing must have played a part. It should also be borne in mind that personality and classroom culture are probably not insignificant factors in CG's willingness to remain vicariously engaged in the task. Frost's (1990) study of teacher intervention in primary design and technology group work provides some insight into the effect of personality and classroom culture on problem solving activities. The teacher of the six children in this study places great emphasis on creating an ethos of independence, cooperation and gender equality which undoubtedly affected the children's behaviour. CB did attempt to involve CG and neither appeared to resent working with the other.

Conclusion

It would appear from this study that:

- the notion of "small to large" is a key concept for speed reduction with geared mechanisms which most children find easy to discover, grasp and apply
- children will be likely to encounter and spontaneously acquire this concept through semi-structured activities with construction kits
- construction of mechanical models following printed or teachers' instructions does not necessarily lead to complete understanding of the principles of geared systems
- "two gears on the same axle" is an anchoring concept which is less likely to be stumbled across without timely teacher intervention
- being able to explain how a geared system works does not necessarily indicate full understanding
- "engagement" with a structured challenging task which focuses on key learning issues is as important as the associated "word work" or practical activity
- girls perform as well, if not better than boys on constructional activities in a supportive environment
- technical vocabulary is less important for the development of design and technology capability than the ideas which the words represent

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