Computer Support for Pupils Collaborating: 
A Case Study on Collisions

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Abstract
This study set out to investigate collaborative learning in pairs of students solving physics problems with a computer. It tested the hypothesis that peer facilitation effects are improved if participants have conflicting models of the task. Subjects working in pairs were more likely to improve their post test scores and to succeed in the problem solving exercise than subjects working totally alone or alone yet in the presence of others. Our main result, which is surprising, suggests that pairs with 'similar' points of view did best.

Keywords — Classroom discourse processes, collaboration and conceptual change, collaborative composition.

1. Introduction
This paper reports the results of a study focusing upon the effects of peer collaboration, peer presence and peer absence when subjects are engaged in computer based physics problem solving activities. We wished to understand more clearly what were the benefits of working with a partner, i.e. can they all be attributed to interactional processes? The influential work of Doise and Mugny [1], has given particular impetus to the study of group composition and their work predicts that group generated conflict stimulates the joint construction of a more advanced concept which is then individually internalised. This study set out to investigate collaborative learning between pairs of students solving physics problems with a computer. It tested the hypothesis that peer facilitation effects are improved if participants have conflicting models of the task. The research takes its direction from Piagetian theory which holds that conflict creates disequilibrium which can then lead students to attempt the construction of new knowledge. If the theory is correct, it should follow that peer collaboration should prove superior to individual learning or situation.

Although there is a body of research focusing on the benefits of peer interaction in the context of computer use (e.g. Howe et al [2], Light and Blaye [3] and O'Malley [4]), there is now a growing interest into the effects of social facilitation in computer based learning. Studies with children have found that peer presence facilitates problem solving (Joiner et al [5]) and that gender too has a mediating effect (Loveridge et al [6]).

In the light of this work we were interested in investigating three issues:

1. Does socio-cognitive conflict maximise learning within pairs?

2. Do pairs perform better than individuals?

3. What effect does working alone, yet in the presence of others, have upon performance?

The results from our study indicate that subjects interacting together as pairs do perform significantly better than subjects working totally alone. However, pupils working simply in the presence of others also exhibit a superior performance to subjects left to struggle alone. The pupils working alone, yet in the presence of others adopted a more systematic investigation of the domain than subjects working totally alone. This observation suggests that peer presence has a motivational effect while interaction within a pair served to draw attention to critical instances in the simulation which could aid further understanding in a domain of known conceptual difficulty.

2. Method

2.1. Subjects
The pupils, involved in these studies comprised of a selection of fifteen year olds (mean age = 15.1 years, sd = 0.67) from an 'all ability' school in Hoddesdon, serving a mainly working-class catchment area. Pupils
all studied a double science G.C.S.E. course, which was taught in a modular fashion. The pupils who took part in the collaborative study were paired according to whether they had similar or different views about the motion of pucks sliding on ice after collision, (data obtained from pre test questionnaire). These groups were balanced in terms of ability level by the class teachers. We chose to study single sex dyads as this was the current practice for teaching within the school. The subjects who worked alone were randomly assigned to the 'coactive' (i.e. used the computer in the presence of others) or the 'single' (used the computer totally alone) condition. The numbers in each group are shown in Table 1 below.

2.2 Procedure
The pupils were firstly pre tested with an extended version of the questionnaire developed by Whitelock et al. This included a prediction task where subjects were asked to predict the subsequent motion of two ice pucks after collision for the following three cases:

Case 1: Puck A is small and light; Puck B is larger and heavier.
Case 2: Puck A is large and heavy; Puck B is smaller and lighter.
Case 3: Puck A and Puck B are identical.

N.B. Puck A always hits a stationary Puck B.

The subjects were questioned about their understanding of kinetic energy and momentum. Most of these later questions were taken from, or adapted from, the APUS Science in schools: Age 15 report, (Welford et al [8]).

Table 1. Numbers of pupils who worked in the 'paired' or 'single' condition when using the PuckLand program.

<table>
<thead>
<tr>
<th>PUPIL GROUP</th>
<th>n</th>
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<tbody>
<tr>
<td>BOYS 'SIMILAR'</td>
<td>22</td>
</tr>
<tr>
<td>BOYS 'DIFFERENT'</td>
<td>18</td>
</tr>
<tr>
<td>BOYS 'COACTIVE'</td>
<td>12</td>
</tr>
<tr>
<td>BOYS 'SINGLE'</td>
<td>14</td>
</tr>
<tr>
<td>GIRLS 'SIMILAR'</td>
<td>22</td>
</tr>
<tr>
<td>GIRLS 'DIFFERENT'</td>
<td>16</td>
</tr>
<tr>
<td>GIRLS 'COACTIVE'</td>
<td>9</td>
</tr>
<tr>
<td>GIRLS 'SINGLE'</td>
<td>9</td>
</tr>
</tbody>
</table>

The pupils were taken (in pairs or as singles) to a sixth form teaching room where a Macintosh SE computer was set up on a table. In the 'coactive' condition i.e. where subjects worked alone yet in the presence of others, the sixth form teaching room contained seven Macintosh computers, and subjects could see each other's screens. Only the pairs were videotaped.

2.3 The Computer Simulation
The PuckLand simulation was written in Hypercard 2.3 for use with the Apple Macintosh computer. It used a direct manipulation approach, (Shneiderman[9]) which allowed students to investigate a series of collisions between two ice pucks. It consisted of a pair of pinball-style flippers on either side of the screen with which subjects could flick pucks. The amount of force with which the flippers hit the puck could be varied, as could the mass of the puck. The ice pucks, ranging from 1 to 100 units of mass, could be dragged into position ready to be struck by the flippers. The initial velocity of the collision was controlled by directly manipulating the angle of the flipper from 90 to 180 degrees in the vertical plane. When the "Go" button was activated the pucks moved towards each other on the screen and were animated with a speed proportional to that set by the initial angle of impact executed by the flipper.

After the pucks collided they moved away from each other with a speed which was calculated from the correct physics formalisms. This meant that the principles of conservation of momentum and kinetic energy were obeyed and again the apparent screen velocities of the pucks was proportional to their calculated values. At the bottom of the screen was a grid which provided numerical information about the amount of energy and momentum that the system had initially, and then subsequent to being run, it showed what the effect of the collision was on these two factors. Every experiment attempted by users of the simulation was automatically logged by the computer.

2.4 Using the Simulation
All the subjects, whether they worked in pairs or alone, had access to their paper and pencil task predictions about the motion of the ice pucks after collision. They were asked to think about their predictions in terms of the sorts of experiments they would like to try with the simulation. Subjects who worked in pairs were asked to actually discuss their predictions with each other and to try and sort out any differences between them before running their experiment on a Mac SE. All subjects then had access to the computer simulation, where they had time to check out their predictions and to experiment with any other situations which interested them. The subjects working as individuals were also actively encouraged to predict their original predictions against the results given by the simulation. (N.B. The length of session for each group was not constrained).

Once the subjects felt they had learnt all they could by experimenting without help with the simulation they were asked to solve three different problems, which were posed in order of difficulty. These problems required the subjects not to predict the result of a collision but to state the original conditions for a given outcome. The problems were as follows:
1. What initial conditions are needed to send the pucks travelling away from each other at the same speed?
2. What initial conditions are needed to make one puck stop after impact?
3. What initial conditions are needed to make pucks of unequal masses move away, after impact, at the same speed?

The purpose of the final phase of the experiment was to ascertain what the pupils had learnt and so they were asked to describe the most important factors that should be taken into account in order to perform the prediction task correctly. Since the pupils working alone could not discuss their results they completed a written summary of their conclusions on their instruction sheet, where they had also recorded their answers to the problem solving exercises. All subjects were post tested, with the same problems and under identical conditions as used in the pretest, 3-4 days after they had used PuckLand.

3. Results

The key finding from this experiment is that, of all the groups tested, pairs do best in terms of post-test gain. The plot of changescores versus group category (see Figure 1) illustrates that both the similar paired condition and the different paired condition perform better than subjects in the single condition. However, the coactives i.e. the pupils who worked alone yet in the presence of others did better than those in the single condition. A one way ANOVA performed on the pre-post test change scores revealed no overall difference according to condition but a post-hoc pairwise comparison revealed a significant difference between the changescores of pupils working individually and those working in similar pairs (Fishers protected LSP p<0.05). Pupils working in similar pairs made a greater pre to post test improvement than those working alone. There were no significant differences between 'girls similar' and 'boys similar' post - test scores but the 'similar girls' pretest (t = 3.2, p=0.1) was significantly lower than the others. The dialogues led us to suspect that the girls had less experiential knowledge of collisions than the boys and this affected their predictions, (i.e. they did not play snooker, football even hockey and did not use analogies from any sporting experiences to make predictions). This finding is similar to that reported by (Johnson and Murphy [10]).

As well as looking simply at improvement on pre to post test scores it was possible to investigate problem solving success when subjects were using the simulation alone and in pairs (See figure 2). The three problems were given in order of difficulty and all the pupils in the paired condition were able to answer question 1.

This was not the case for 'boys coactive' and boys and girls working alone. In fact the single condition for problem 1 is significantly different from that of the 'similar', 'different' and 'coactive' conditions (Fishers protected LSP p<0.05).

Figure 1. Graph to illustrate change scores versus group category.

\[
\begin{array}{c|c|c|c|c}
\hline
\text{Category of subject tested} & 0 & 1 & 2 & 3 & 4 \\
\hline
\text{Cell mean of change} & 0 & 0.5 & 1 & 1.5 & 2 \\
\hline
\end{array}
\]

Key: 1 = 'similar', 2 = 'different', 3 = 'coactive', 4 = 'single'.

For problem 2 and 3 there were no significant differences across groups. In fact Problem 3 proved to be too difficult for most of the subjects. This data supports the Piagetian hypothesis that working in pairs should be superior to working alone. However we have also found that pupils working in the presence of others have better scores than those working totally alone. Therefore further analysis of the number and range of experiments performed with PuckLand was undertaken to find reasons for these group differences.

The pupils in the single condition spent significantly less total time using PuckLand, (Fishers protected LSP p<0.05) than those in the similar, 'different' and 'coactive' conditions. There is no significant difference between the time spent by pairs in the exploratory phase but significant differences between the pairs and the single condition and the pairs and the coactive conditions in this phase. The pairs, like the coactives, spent longer exploring the domain before they wanted to complete the problem solving tasks. These results suggest that one of the factors contributing to problem solving success with this simulation is allowing enough time to become familiar with the domain before rushing into the problem solving.

One very interesting finding from the analysis is that the girls benefited more than the boys from the 'coactive' condition. They persevered longer with the experimental phase than the boys in the 'coactive' condition. They were more conscious of what their peers were doing throughout the whole experiment, making use of the auditory clues provided by the simulation. For example when the sticks hit the puck there is a sound which is followed by a louder noise when both pucks collide. They used this cue to assess how their peers were progressing and hence continued with the
work while they understood others were persevering with the task in hand.

Figure 2. Percentage of pupils who solved each of the Puckland problems.

To summarise: the pairs investigated all the scenarios where our previous work has shown pupils experienced conceptual difficulty. The 'coactives' and 'singles' did not exhibit an identical behaviour but unlike the pairs the coactives experimented with limiting conditions cases. The lack of investigation of critical events by pupils working alone suggests that a partner can draw attention to unexpected phenomena. This aspect was the missing ingredient from the 'coactive' and 'singles' conditions. It is suggested that working in pairs can encourage a 'predict, observe and explain' modus operandi which in turn can facilitate subjects "seeing" the unexpected phenomena.

4. Conclusion

The results indicate that on this computer-based investigation subject working in pairs were more likely to improve their post test scores and to succeed in the problem solving exercise than subjects working alone. However there was no significant difference between the pairs. The Video analysis of the interaction between the pairs revealed more instances of conflict among the different pairs however, there were far fewer conflicts than expected, in fact only 28 in total with 16 recorded among the different pairs. All subjects however, tried to resolve these conflicts but only one remained unresolved among the similar pairs and three were unresolved among the different pairs. Two separate strategies were employed to resolve conflict these were achieved by appealing to the computer for the correct answer and secondly by talking the problem through by themselves. Resolution of conflict by the computer was used more by 'different' pairs and the other strategy of talking through the problem was used more by the 'similar' pairs. This result suggests that cooperative construction of shared meaning maybe a more important consideration than conflict in successful collaboration (Barbeil and Light [11]).

We found that subjects working in the 'coactive' or 'singles' condition perform more experiments than the pairs. However, it was not the number but type of experiments investigated that was an important factor in understanding the nature of collisions. Both the pairs and the singles spent more time exploring the domain before attempting the problem solving exercises. Not only were the range of experiments different within the groups but more importantly the approach. It appeared that the pairs did better because they adopted a "predict, observe, explain" modus operandi which was not attempted by the pupils working as individuals in the 'coactive' or in the single condition. This observation suggested that peer presence had a motivational effect and that anxiety was lowered when subjects worked in the presence of others. This appeared reasonable conclusion since two subjects in the single condition were so stressed they abandoned the experiment less than half way through. The 'coactives' performed better than the singles and also felt they had learnt more as revealed by their comments at the end of the experiment.

Similar' pairs did perform significantly better than pupils working totally alone and although they performed better than the 'coactives', there was a benefit not only from peer interaction but also from peer presence. In our case peer presence prevented subjects from giving up, they felt more relaxed and persevered in an productive fashion exhibiting less trial and error behaviour than the singles. The magnitude of such peer presence effects is controversial (e.g. Light et al [12], and Mevarech et al [13]).

Our results suggested that a "predict, observe, explain" methodology (see e.g. Champagne et al [14], aids subject understanding of a domain. The adoption of this strategy has proved to be successful when used by both Hennessy et al [15] and Howe et al [2]. Although Howe's work has found that most benefits occur when members of a pair have different views we have found that children can progress without necessarily having reached a more advanced solution during interaction. An important finding from our study is that the performance gains by the 'coactive' group suggested that it was not just the interaction but the presence of others sharing the same task which lowered anxiety levels and increased subject motivation although we did not collect measures of these, our results are based on observations of subject behaviour. To conclude our main result is surprising and does not support one popular view of the benefits of collaboration. Oursubsidiary results cast light on the role of experiments in developing pupils conceptual understanding, modes of collaborative working and the design of interactive learning environments.

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