Undoing one's learning

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Abstract

Post-task questionnaires presented at the end of complex problem solving tasks have revealed dissociations between participants' performance and their declarative knowledge of the task and their behavior during the tasks (e.g., Berry, 1991; Berry & Broadbent, 1984). This kind of dissociation has been taken as evidence for functionally separable inductive reasoning processes (i.e. implicit reasoning vs. explicit reasoning). Contrasting this position, studies of goal specificity effect (i.e. Non-goal orientated instead goal-orientated learning leads to global processing of task information and successful transfer of knowledge) show that individuals have access to, and can accurately report on their hypothesis testing behavior during complex problem solving tasks (e.g., Burns & Vollmeyer, 2002). To reconcile these competing positions Buchner, Funke and Berry (1995) proposed that, rather than evidence of dissociations between implicit and explicit inductive reasoning, this kind of evidence suggests differences in the diversity of learning experiences that are generated during the tasks. The aim of the present study was to investigate Buchner et al's (1995) claims. In order to achieve this, a novel procedure was employed in which participants solved two control tasks under Non-goal orientated learning conditions. For half, the learning phase from the first task was recorded and replayed in the second task (i.e. restricted learning experiences). For the remaining half a different learning phase from their first was presented in the second task (i.e. diverse learning experiences). The findings showed decrements in control performance under conditions in which the diversity of the learning experiences was restricted; these findings are discussed in light of dual system frameworks.

Complex Dynamic Control Tasks

Dynamic control tasks are essentially causal learning environments in which problem solvers are required to detect the underlying relationship between a set of inputs and their effects on a set of outputs. There are many practical situations which can be conceived as involving complex dynamic industrial process operations (e.g., nuclear power plant, recycling plant, waste disposal plant, water purification plant) and that are complex dynamic systems (e.g., naval mine sweeping, flying, air-traffic control, car driving). Many (e.g., Berry, 1991; Berry & Broadbent, 1984, 1987, 1988; Lee, 1995; Lee & Vakoch, 1996) argue that the ability to control and maintain dynamic systems is implicit: that is, the knowledge that is acquired and utilized is beyond the individual's conscious awareness. The reason for this position is that the knowledge necessary to perform complex control task is described as procedural and the representations encoded are not arranged in a way that allows them to be manipulated, decomposed, and analyzed intentionally (bottom-up learning). Others claim that skilled problem solving is an example of intentional top-down processing that includes hypothesis testing which is dependent on representations being available for conscious manipulation (top-down learning). Studies investigating the influence on top-down processes in control tasks have reported an effect referred to as the goal specificity effect. When people solve a problem following a specific goal (SG), they examine information that is only relevant to the identified goal at the cost of having a superficial understanding of the problem (Sweller, 1988). In contrast, when solving a task under a non-specific goal (NSG) problem solving search is unrestricted, and so people have been shown to gain a broader and deeper understanding of the problem (Miller, Lehman, & Koedinger, 1999). Studies examining the goal specificity effect show that there is a close correspondence between explicit knowledge of input-output relations and behavioral evidence of performance on complex dynamic control tasks, whereas studies of implicit reasoning processes show dissociations between self reports and control performance.

Accurately determining the conditions that make tasks invoke implicit processes has been the subject of some controversy (Osman, 2004; Osman & Stavy, in press). The reason for this controversy is that some argue that implicit processing is a primary function and therefore most processing that goes on is implicit, whereas others begin with the position that all processing is explicit until proven otherwise. Consequently there is some dispute as to the kinds of tests that should be used to examine the accessibility of knowledge, and thus far, it has been shown that the accessibility of knowledge is relative to the particular method used to examine it. For instance, with extended experience of a complex dynamic control task Stanley et al (1989) asked individuals to verbally express their knowledge of the task, on returning to the task, individuals' performance dramatically improved; this suggests an association between verablizable knowledge of the task and inductive reasoning processes. The facilitative effects of verbalization on control performance has also been demonstrated by Sanderson (1989) in which long practice sessions with a complex dynamic control task lead to accurate verbalizable knowledge of the task. Clearly the evidence for dissociations between self report measures and behavioral data on complex dynamic control tasks is far from conclusive.

An Illustration of a Complex Dynamic Control Task

Typically complex dynamic control tasks involve several input variables which are continuous (e.g., concentration levels of salt, carbon, and lime) and that are connected via a complex causal structure or rule to several output variables that are also continuous (e.g., Chlorine concentration, Oxygenation levels, temperature) (See Figure 1). The example used here is taken from Burns and Vollmeyer's (2002) task which was originally based on a water tank purification system. In their system the starting values of the inputs were set to 0, and those of the outputs are: Oxygen = 100, Chlorine concentration = 500, Temperature = 1000, and the objective was to learn the causal structure and numerical relationship between the inputs and outputs; which is described as linear, but with constant value added to each connection.

Insert Figure 1 about here

Thus, learning about the system and then attempting to control it requires that participants accurately incorporate the continuous feedback they receive on the output variables while changing the input variables. For instance, if on the first trial a participant decides to change the level of the input variable Carbon to 100 units, the value for the output Temperature will be 1104 (i.e., 1000 (which is the starting value) + 100 (value of Carbon) + 4 (the added value)). Because the input Carbon belongs to a common effect causal structure, the output Chlorine Concentration is also affected, and its value will be 599.5 (i.e., 500 (which is the starting value) + 100 (value of Carbon) + -0.5 (the added value)). If on trial 2 the value of the input Salt is changed, the output values of Temperature and

Oxygenation will remain the same as the previous trial, and only Chlorine Concentration will change, because it is the only output connected to the input Salt.

Conflicting theoretical issues

Where both research interests (implicit inductive reasoning & goal specificity) in the control task paradigm meet is in the discovery of the transfer limitations of knowledge gained during induction. Studies of control tasks devised to examine implicit learning outline the task environments that enable transfer of knowledge (i.e. perceptual similarity of transfer tasks, saliency of input-output relations). Studies of goal specificity detail the properties of the instruction that can lead to successful transfer (i.e., NSGs leads to global processing of task information and successful transfer of knowledge), and in both these research domains, instance based knowledge or its equivalent SG based knowledge, does not transfer beyond situations similar to those in which it was acquired.

Where both research interests (implicit learning & goal specificity) differ, is the level of self insight that they posit individuals have of the processes they use in control tasks. Berry (Berry, 1991; Dienes & Berry, 1997) claims that people only have access to the end products of the processing but not the actual process involved in generating them (e.g., Berry & Broadbent, 1984, 1987; 1988; Dienes & Fahey, 1995, 1998). The parallels between action (procedural learning) and implicit learning, and observation and explicit learning have also been explored (e.g., Berry, 1991). Consistent with this, there is evidence to suggest that there is good control performance in complex dynamic control tasks under conditions of active learning and poorer performance when learning takes place through observation (e.g. Berry, 1991; Lee, 1995; Zang et al, 2004). This is at odds with evidence from studies of the goal specificity effect which show a correspondence between verbal self-reports of problems solving behavior and behavioral evidence of problem solving ability (e.g., Burns & Vollmeyer, 2002; Miller, Lehman, & Koedinger, 1999). In addition, performance on direct and indirect measures is shown to be associated (Burns & Vollmeyer, 2002); in particular, this has been reported in complex control systems that adopt a non-salient input-output structure with multiple causal links from inputs to outputs (e.g., Burns & Vollmeyer, 2002; Vollmeyer, et al, 1996).

Buchner et al's (1995) attempt to reconcile the dissociations between implicit and explicit learning reported in studies of implicit learning is also inconsistent with evidence from studies of the goal specificity in control tasks. Rather than evidence of dissociations between implicit and explicit learning processes, Buchner et al (1995) claim that conflicts between good performance on indirect (implicit) measures of knowledge and poor performance on direct (explicit) measures reflects differences in the range of learning experiences gained in a control task. Focused learning experiences lead to the accumulation of homogenous instance based knowledge which leads to good performance on indirect measures but poor explicit knowledge tapped by direct measures. Unrestricted learning experiences lead to good performance on direct test of knowledge because a wider range of instances of input-output states are accumulated, but at the cost of poor performance on indirect tests, because accurately controlling the system requires repeated exposure to similar learning experiences.

Buchner et al (1995) claim that to ensure good control performance it is necessary to maintain similar learning instances during training and limit the exploration of the system and predict that the diversity of learning experiences is inversely related to control performance. The corollary to this is that the diversity of learning experiences should also be inversely related to the transfer of control performance to control tasks that are perceptually and structurally similar to those in which knowledge was acquired. This is at odds with evidence that shows focused SG learning leads to poor control performance and poor transfer of control performance compared to unrestricted NSG learning (e.g., Burns & Vollmeyer, 2002; Vollmeyer, et al., 1997). In addition, based on Buchner et al's claims, participants experiencing a limited range of learning experiences should fail to show accurate self insight, as detected by self report measures, compared with those experiencing a diverse range of learning experiences.

Experiment 1

The contradiction between the two approaches studying inductive processes in control tasks leaves open the question of whether experiencing a diverse range of learning instances in a control task leads to poor control performance and poor transfer compared to experiencing a restricted but well practiced range of learning experiences. The innovation of the present study is to contrast the effects during NSG learning on the transfer of control performance across perceptually dissimilar but structurally similar control tasks, and when learning experiences are limited but repeated compared with learning experiences that are diverse. By doing this, the present study examines the prediction that the diversity of learning experiences should be inversely related to control performance and transferability of this skill to similar task domains.

The second purpose is to examine the effects on performance when learning was action-based or observation-based. To investigate this, participants either observed the learning phase in second task (Observe-self, Observe-other), or they actively interacted with the system (Act-on-self, Act-on-other). If procedural learning is necessary for good performance in control tasks, then the performance of observation-based learning conditions would be compromised compared to the performance of action-based learning conditions. It was also hypothesized that if participants in action-based learning conditions were learning implicitly, then they would be unable to accurately detect their own from another's learning compared with the observation-based learning conditions; this is because the representations acquired by participants in observation-based learning conditions would be explicit.

Method

Complex Dynamic Control Tasks: The two control tasks used in the present study were based on Burns and Vollmeyer's (2002) Water tank problem solving task. The water tank task version involved learning to control a linear system (Water tank system) which consisted of three inputs (substances: Salt, Carbon, Lime) that were connected to three outputs (measures: Oxygenation, chlorine Concentration, Temperature) (see Figure 1).

Furthermore, there was a constant value added to each input-output link. The second control task was structurally identical to the first with the exception that the context and visual layout of the task was changed. Participants were told that they were newly recruited ghost hunters and that they had returned from a field experiment. It was their job to learn the relationship between three pieces of equipment that had been used in the field and the phenomena that each machine detected. The three machines (i.e. GGH meter, Anemometer, TrifieldMeter) represent the three inputs equivalent to the Water tank problem devised by Burns and Vollmeyer, and the three phenomena that were detected (i.e. Electro Magnetic Waves, Radio Waves, Air Pressure) represent the three outputs. The control element of the task was to modify the levels of the readouts of the phenomena by manipulating the dials on each machine.

Participants: Forty-eight students from University College London volunteered to take part in experiment and were paid £6 for their involvement. They were randomly allocated to one of the four conditions (Observe-self, Observe-other, Act-on-self, Act-on-other) with twelve in each. Participants were tested individually. The order of presentation of the two dynamic control tasks (i.e. the Water tank system, Ghost hunting task) was randomized for each participant.

Design: The experiment was a 2x2 between subjects design with two types of exploration phase (self, other) and two types of learning condition (action, observation). All participants were required to solve two complex dynamic control tasks. The order in which participants were presented the two control tasks was randomized, (hence forth the control tasks will be referred to as Problem 1 [i.e. the first control task participants solved] and Problem 2 [i.e. the second control task participants solved]. Each problem comprised a learning phase referred to as the *Exploration phase* which consisted of 12 trials, and two control tests referred to as *Control Test 1* and *Control Test 2*; in these test participants were required to demonstrate their ability to control the system to pre-specified criteria.

The exploration phase in Problem 1 was experienced in the same way by all participants taking part in the study. The critical manipulation in the present study was the format in which the exploration phase was presented (observational, procedural) and whether the learning experiences were identical to Problem 1 (self) or different to Problem 1 (Other).

In Problem 1 in the *Exploration phase* for each trial participants were free to change as many inputs as they liked. Once they were satisfied with their changes to the inputs, participants would click on a button labeled 'output readings' and this would reveal the values of all three outputs. This procedure would complete a trial. For action based conditions (Act-on-self, Act-on-other) the inputs changed and the values they were changed by were recorded for each trial of the exploration phase for each participant. In Problem 2, prior to starting the exploration phase, participants were presented with a record sheet with the trial history from the exploration phase of Problem 1. Participants were instructed to change inputs on each trial according to the value on the record sheet they were given.

The Act-on-self, were presented with the trial history of their own exploration phase from Problem 1, the Act-on-other condition were yoked to a participant in the Act-on-self condition, and therefore were presented with the trial history of an exploration phase different to that experienced by them in Problem 1.

Insert Figure 2 about here

For the observation conditions (Observe-self, Observe-other) in the exploration phase of Problem 2 participants were unable to directly intervene by selecting the inputs they wanted to change and the values they wished to change them by. Instead observation-based learning conditions tracked changes to input values and the effect on the output values for each trial. The Observe-self condition tracked the changes to the inputs and the input value changes that they had chosen themselves in the exploration phase of Problem 1. Observe-other condition was yoked to a participants from the Observe-self condition and so tracked the changes to the inputs and the input value changes that were different those they had made themselves in the exploration phase of Problem 1.

Figure 2 depicts the design of the experiment. The large white and grey boxes depict each problem that was solved. In Figure 2 the exploration phase of self experience conditions (i.e. Observe-self, Act-on-self) is shaded in the same color in both Problem 1 and Problem 2. For these conditions the problem content of Problem 1 and 2 differed, but exploration phases of each problem were matched. In Figure 2 the exploration phase of experience other conditions (i.e. Observe-other, Act-on-other) is shaded differently in both Problem 1 and Problem 2. For these conditions the problem content of Problem 1 and 2 differed as did the exploration phases of each problem. It should also be noted that the shading of the exploration phase in Problem 2 is identical to that of the exploration phases of the experience self conditions.

Thus, in the exploration phase the input values that participants had selected on each trial in the exploration phase of Problem 1 were recorded along with the corresponding output values, and for Experience Self conditions (Observe-self, Act-on-self) these were presented to them in the exploration phase of Problem 2. The experience other conditions (Observe-other, Act-on-other) were yoked to participants in the experience self conditions, that is, in the exploration phase of Problem 2 the experience other conditions were presented with the exploration phase of a participant from the experience self condition. Thus, all participants made their own decisions in the first exploration phase, but in the second exploration phase, half of the participants were presented with their own exploration phase again, while the remainder experienced a different exploration phase to their self generated one.

Procedure: Participants were told that they would be taking part in a problem solving task. They were also assured that throughout the task, were they to encounter any difficulties, they should ask the experimenter for assistance. On completion of the Problem 1 participants were then told that they would be presented with another problem solving task. At no stage throughout the experiment were participants informed that the two problems were similar, or were they given advanced warning that they would be performing two problems.

Exploration phase: All participants were presented with the same computer display which was similar to Figure 1 with the exception that the connections and added contrast value of each connection were not presented.

Control test 1: In this phase all participants were required to change the input values to achieve the following output values: Oxygen = 50, Chlorine concentration = 700, Temperature = 900. Participants were allocated 6 trials in which they were to reach and then maintain the output values given.

Control test 2: As with Control Test 1, all participants were now required to change the input values to achieve given output values. However, the required output values were now: Oxygen = 250, Chlorine concentration = 350, Temperature = 1100.

Posttest question: Before being debriefed, at the end of the experiment participants were informed that there were two conditions in the experiment and that they were randomly allocated to one. It was explained that in one condition participants were presented with their exploration phase from Problem 1 again in Problem 2, or they were presented with the exploration phase of another participant in Problem 2. Participants were asked which of the two conditions they took part in, and what they based their decision on.

Scoring: Control Test Error Scores: The procedure Burns and Vollmeyer used in scoring performance in the Control tests was adopted here. Success in achieving the goal states in each phase was computed as the sum of the absolute differences between each goal value and the value produced for each of the three outputs. All analyses of these scores are based on the mean error, for Control test 1 averaged over all six trials and averaged across all three output variables. A log transformation (base 10) was applied to the error scores of each individual participant for each round to minimize the skewedness of the distribution of scores. Control test 2 scores were calculated in same way as the Control test 1 scores. This scoring scheme was applied to all control tests presented in this study. For Control test error scores in each phase a lower score indicates better performance.

Results

Figure 3 shows that overall error scores in Control Test 1 appear to be lower than error scores in Control Test 2. Figure 3 also indicates that for Control test 1 and Control test 2 the error scores of the Observe-self and Act-on-self appear to have decreased in Problem 2 compared to Problem 1. In contrast, the error scores of the Observe-other and Act-on-other conditions appear to be stable across Problem 1 and 2. To examine the possible interaction between the diversity of learning experiences and control performance across Problem 1 and 2 the following analyses were conducted.

Performance on Control Test 1 and 2: An initial comparison of the control performance of both conditions in Problem 1 was made, to rule out the possibility that initial group differences influenced any later main effects detected as a result of the critical manipulations included. A 2x2x2 ANOVA with Control test (Control Test 1, Control Test 2) as a within subject variable, and exploration phase (Self, Other) and learning format (action, observation) as between subject factors, was conducted on mean error scores. The analysis revealed no significant main effect of Control test, $F(1, 44) = 4.86$, MSE = 0.14, $p < 0.05$. There was no significant main effect of exploration phase, $F(1, 44) = 0.30$, MSE = 0.02, and no significant main effect of learning format, $F(1, 44) = 0.005$, MSE = 0.0004, and no significant interactions. Thus, there was no significant difference in control performance between conditions in Problem 1 based on the exploration phase or learning format; however, the overall performance of both conditions differed significantly between control tests, suggesting that the control tests may have differed in difficulty. This is consistent with the findings reported in Burn and Vollmeyer's study, on which the control test used in the present study was based.

Insert Figure 3 about here

Control Test Error Scores: The following analyses were conducted on the mean error scores calculated for each participant. A 2x2x2x2 ANOVA was carried out with Control Test (Control Test 1, Control Test 2) and Problem (Problem 1, Problem 2) as the within subject factors, and exploration phase (Self, Other) and learning format (action, observation) as between subject factors.

The analysis revealed a significant main effect of Control Test, $F(1, 44) = 11.561$, MSE = 0.39, $p < 0.002$. There was no significant main effect of Problem $F(1, 44) = 1.88$, MSE = 0.1, and no main effect of learning format $F(1, 44) = 0.04$, MSE = 0.004. There was a significant main effect of exploration phase on error scores $F(1, 44) = 7.06$, MSE = 0.72, $p < 0.05$, and a significant Exploration phase x Problem interaction $F(1, 44) = 21.08$, MSE = 1.14, $p < 0.0005$. Thus the results confirmed the pattern of findings indicated in

Figure 3 that overall, there was a difference in performance between Control test 1 and 2. There was no overall difference between error scores in Problem 1 and 2, and no evidence that the learning format influenced the pattern of error scores. To locate the source of the interaction, tests of simple main effects were carried out. Because learning format was not found to have a significant effect on error scores, error scores were collapsed across Observe-self and Act-on-self conditions, and across Observe-other and Act-on-other conditions. The significant decrease in performance across problems for the experience self conditions was confirmed by planned comparisons of error scores in Control Test 1 $t(23) = -23.23$, $p< 0.0005$, and Control Test 2 $t(23) = -17.77$, $p< 0.0005$. The increase in performance across problems for the experience other conditions was not statistically confirmed by planned comparisons of error scores in Control Test 1 $t(23) =1.91$, $p= 0.067$, and Control Test 2 $t(23) =1.98$, $p< 0.061$, although both tests approached significance.

Insert Table 1 about here

Table 1 presents the proportion of correct responses to the posttest question. Pearson's chi-squared analysis was carried out on the frequencies of correct responses and revealed that there was no significant difference in the accuracy of participants response to the recognition question, $\chi^2(1) = 0.88$, $p> 0.05$. Responses in each group indicated that participants were able to accurately identify which experimental condition they took part in.

Discussion

The evidence from this study did not confirm Buchner et al. (1995) prediction that the diversity of the learning experiences is inversely related to control performance in dynamic control tasks. Instead the findings from the present study revealed that by limiting the learning experiences to those previously experienced control performance is adversely affected to the extent that it produces a negative learning effect. However, this pattern of findings is also not predicted by the position that restricted goal learning reduces control performance relative to unrestricted goal learning which produces a varied set of learning experiences. However, consistent with this position, there was evidence to suggest that increasing the range of learning experiences does lead to improved control performance.

There was no evidence to suggest that control performance was adversely affected by the observation–based learning format of the exploration phase compared to the procedural based learning version. In addition, it should be noted that, although the exploration phase in Problem 2 for the Act-on-self and Act-on-other conditions was procedualized, the knowledge that was acquired and utilized at this stage is likely to have been consciously available to participants. Otherwise, they would not have been able to make accurate responses to the post-test question, in addition there was no difference between the accuracy of their self reports and those of the observation based learning conditions.

The evidence from Experiment 1 suggests that, independently of whether the format of the exploration phases in Problems 1 and 2 was the same or different, negative transfer of control performance, occurs when learning experiences are restricted, and positive transfer occurs when the learning experiences are diverse. However, in Experiment 1 the underlying structures of Problems 1 and 2 were identical, but the problems were perceptually dissimilar. In order to further examine the reliability of the effects reported, Experiment 2 was devised, in which Problem 1 and Problem 2 were perceptually and structurally identical.

In addition, the evidence from Experiments 1 showed that there are detrimental effects on the transferability of knowledge when the diversity of learning experiences is reduced to re-experiencing those that were self-generated. Moreover, in response to the post-test question, participants showed above chance accuracy in the identification of the source of exploration phase in Problem 2. Although, at the time of test, participants claimed that they were unaware that they were being presented with their own previous learning experiences, they reported making similarity based judgments of the two exploration phases. As a result of this, participants in the self-experience conditions may not have been motivated to pay attention to the exploration phase in Problem 2, because of its similarity to the exploration phase in Problem 1. For this reason, there was no reinforcement of the learning instances experienced, because participants were not paying attention. Conversely, for the diverse experience conditions, the dissimilarity of their own exploration phase in Problem 1 to that presented in Problem 2 may have motivated participants to pay closer attention, which in turn increased their understanding of the problem and facilitated transfer across complex dynamic control tasks. To explore this, the following experiment was designed to manipulate the attentional focus on learning experiences by disguising the origin of the learning phase.

Experiment 2

Experiment 1, showed that negative transfer of control performance and causal knowledge is found in conditions in which participants are exposed to self-generated learning experiences. Along with this, participants consistently showed accurate self-insight in response to post-test questions. To examine whether the awareness of self-generated learning prevents successful transfer of control behavior through reinforcement of learning experiences, Experiment 2 included four conditions (Act-on-Self, Act-on-Other, Disguised-Act-on-Self, Disguised-Act-on-Other). The Act-on-Self and Act-on-Other conditions were identical to Experiment 1. The Disguised-Act-on-Other condition was identical to the Act-on-Other condition with the exception that participants were informed that the learning phase in Problem 2 was their own when in actual fact it belonged to another participant. The Disguised-Act-on-Self condition was identical to the Act-on-Self condition with the exception that participants were informed that the learning phase in Problem 2 belonged to another participant when in actual fact it was their own. It was hypothesized that, following these instructional manipulations, if the reinforcement of learning experiences is necessary for the transfer of control performance, then there should be improved control performance in Problem 2, compared to Problem 1, for the

Act-on-Self and Disguised-Act-on-Self conditions, and their improvement should be greater than the Act-on-Other and Disguised-Act-on-Other conditions. If diversity of the learning instances experienced is necessary for the transfer of control performance, then there should be improved control performance in Problem 2, compared to Problem 1, for the Act-on-Other and Disguised-Act-on-Other conditions, and their improvement should be greater than the Act-on-Self and Disguised-Act-on-Self condition.

Method

Participants: Forty-eight students from University College London volunteered to take part in experiment and were paid £6 for their involvement. They were randomly allocated to one of the four conditions (Act-on-Self, Act-on-Other, Disguised-Act-on-Self, Disguised-Act-on-Other) with twelve in each. Participants were tested individually

Design: Experiment 2 was a mixed design that included two between subject variable examining the effects of the diversity of learning experiences, by comparing two conditions (self, other), and examining the effects of introducing an instructional manipulation that disguised the source of the learning phase in Problem 2 (disguised, unconcealed). There were two within subject variables examining the transfer of control performance between two tests of transfer (Control Test 1, Control Test 2) and across two complex dynamic control tasks (Problem 1, Problem 2). With the follow two exceptions the design of Experiment 2 was identical to that used for the Act-on-Self and Act-on-Other conditions used in Experiment 1: Participants were presented with the same problem twice, and that for half of the participants taking part the origin of the learning phase in Problem 2 was disguised.

As with Experiment 1, all participants in Experiment 2 completed Problem 1 in an identical manner. Participants began with the Exploration phase in which they actively manipulated the inputs by changing their values, and monitoring the effects on the outputs, by tracking the changes to their values. The inputs that were changed and the values they were changed by were recorded for each trial of the exploration phase for each participant. In Problem 2, prior to starting the exploration phase, all participants were presented with a record sheet with the trial history from the exploration phase of Problem 1. Participants were instructed to change inputs on each trial according to the value on the record sheet they were given. For the Act-on-Self and Act-on-Other conditions the procedure used was identical to that used in Experiment 1. The Act-on-Self condition were presented with the trial history of their own exploration phase from Problem 1, the Act-on-Other condition were yoked to a participant in the Act-on-Self condition, and therefore were presented with the trial history of an exploration phase different to that experienced by them in Problem 1.

The procedure used for the Disguised-Act-on-Self and the Disguised-Act-on-Other conditions differed from the Act-on-Self and Act-on-Other conditions in one respect. Prior to the presentation of Problem 2, the Disguised-Act-on-Self condition was informed that they would be presented with a record sheet of the learning phase of a participant who had taken part in the same problem. In actual fact, the record sheet was of their own exploration phase in Problem 1. Prior to the presentation of Problem 2, the Disguised-Act-on-Other condition was informed that they would be presented with a record sheet based on the learning phase they had generated in Problem 1. In actual fact, the record sheet belonged to a participant from the Disguised-Act-on-Self condition. In order for the instructional manipulation to be maximally effective, the Disguised-Act-on-Other condition were instructed that the record sheet was based on, rather than identical to, their learning phase in Problem 1.

Thus, in the exploration phase the input values that participants had selected on each trial in the exploration phase of Problem 1 were recorded along with the corresponding output values, and for experience self conditions (Act-on-Self, Disguised-Act-on-Self) these were presented to them in the exploration phase of Problem 2. The difference between the two experience-self conditions was that the source of the exploration phase of Problem 2 was disguised. The experience-other conditions (Act-on-Other, Disguised-Act-on-Other) were yoked to participants in the experience self conditions, that is, in the exploration phase of Problem 2 the experience other conditions were presented with the exploration phase of a participant from the experience self condition. The difference between the two experience-other conditions was that the source of the exploration phase of Problem 2 was disguised. Thus, all participants made their own decisions in the first exploration phase, but in the second exploration phase, half of the participants were presented with their own exploration phase again, while the remainder experienced a different exploration phase to their self generated one.

Procedure: Problem 1 and Problem 2 comprised an *Exploration phase* consisting of 12 trials, and two test phases (Control Test 1 and Control Test 2) in which participants were required to change the input values to achieve and maintain specific output values (these were identical to those used in Experiment 1). After completing Problem 2 all participants were presented with the same posttest question used in Experiment 1, which was designed to examine participants self insight.

Results

Figure 4 shows that overall error scores in Control Test 1 appear to be lower than error scores in Control Test 2. Figure 3 also indicates that for Control Test 1 and Control Test 2 the error scores of the Act-on-Self and Disguised-Act-on-Other appear to have increase Problem 2 compared to Problem 1 indicating a decrement in performance across problems. In contrast, the error scores of the Act-on-Other and Disguised-Act-on-Self conditions appear to be decrease in Problem 1 compared to Problem 2 indicating an improvement in performance across problems. To examine the possible interaction between the diversity of learning experiences and control performance across Problem 1 and 2 the following analyses were conducted.

Insert Figure 4 about here

Performance on Control Test 1 and 2: An initial comparison of the control performance of both conditions in Problem 1 was made, to rule out the possibility that initial group differences influenced any later main effects detected as a result of the critical manipulations included. A 2x2x2 ANOVA with Control test (Control Test 1, Control Test 2) as a within subject variable, and exploration phase (Self, Other) and instruction (Disguised, Unconcealed) as between subject factors, was conducted on mean error scores. The analysis revealed no significant main effect of Control test, $F(1, 44) = 6.22$, MSE = 0.13, $p < 0.05$. There was no significant main effect of exploration phase, $F(1, 44) = 0.43$, MSE = 0.02, and no significant main effect of instruction, $F(1, 44) = 0.39$, MSE = 0.02, and no significant interactions. Consistent with Experiment 1, there was no significant difference in control performance between conditions in Problem 1 based on the exploration phase or instruction; however, the overall performance of both conditions differed significantly between control tests, suggesting that the control tests may have differed in difficulty.

Control Test Error Scores: The following analyses were conducted on control test mean error scores. A 2x2x2x2 ANOVA was carried out with Control Test (Control Test 1, Control Test 2) and Problem (Problem 1, Problem 2) as the within subject factors, and exploration phase (Self, Other) and Instruction (Disguised, Unconcealed) as between subject factors.

The analysis revealed a significant main effect of Control Test, $F(1, 44) = 9.87$, MSE = 0.24, $p < 0.005$. There was no significant main effect of Problem $F(1, 44) = 0.23$, MSE = 0.008, and no main effect of learning format $F(1, 44) = 0.63$, MSE = 0.025, and no main effect of exploration phase on error scores $F(1, 44) =0.63$, MSE = 0.025. However, there was a significant Exploration phase x instruction Interaction, $F(1, 44) = 6.77$, MSE = 0.26, $p < 0.05$. In addition, the analysis revealed a significant Exploration phase x Problem x Instruction interaction $F(1, 44) = 24.32$, MSE = 0.81, $p < 0.0005$. Thus the results confirmed the pattern of findings indicated in Figure 3. To locate the source of the interaction, tests of simple main effects were carried out. There was no interaction between Control test and Problem and so error scores in Control Test 1 and Control Test 2 from Problem 1 were collapsed, and Control Test 1 and Control Test 2 from Problem 2 were collapsed. The significant decrease in performance across problems for the Act-on-Self condition was confirmed by planned comparisons of error scores between Problem 1 and Problem 2 $t(23) = -4.22$, $p < 0.0005$. There was a significant increase in performance across problems for the Act-on-Other condition, $t(23) = 3.11$, $p < 0.005$, and the Disguised-Act-on-Self condition, $t(23) = -3.45$, $p < 0.005$. There was no significant difference in performance between Problems 1 and 2 for the Disguised-Act-on-Other condition $t(23) = -1.11$.

Table 1 also presents the proportion of correct responses to the posttest question in Experiment 2. The proportion of participants responding correctly in the Disguised-Act-on-Other condition appears to be reduced compared with the other three conditions included in Experiment 2. However, Pearson's chi-squared analysis was carried out on the frequency of correct responses and revealed that there was no significant difference in the accuracy of participants responses to the posttest recognition question, $\chi^2(1) = 0.88$, $p > 0.05$.

Discussion

Consistent with Experiment 1, the evidence from Experiment 2 showed that the control performance of the Act-on-Self condition in Problem 2 significantly decreased compared to Problem 1, and that the control performance of the Act-on-Other condition increased across problems. However, in the Disguised-Act-on-Self condition in which participants attributed the learning phase in Problem 2 to another participant, performance in the control tests improved compared to Problem 1. However, in the Disguised-Act-on-Other condition in which participants attributed the learning phase in Problem 2 to themselves, performance was equivalent in Problem 1 and 2. Thus, the facilitative effects of experiencing diverse learning instances reported in Experiments 1 were not found in Experiment 2. Instead, there was no difference in performance between Problem 1 and 2 for the Disguised-Act-on-Other condition. Thus, neither of the hypotheses examined were confirmed by the evidence from Experiment 2. Instead the evidence suggests that the diversity of the experiences encountered and belief in experiencing diverse learning instances leads to improvements in control performance.

Although not significant, the instructional manipulation appeared to influence the accuracy of responses to the post-test question. Less than half of participants in the Disguised-Act-on-Self condition correctly identified which condition they were in, suggesting that most participants were willing to believe that the self-generated learning phase that they were presented with in Problem 2 belonged to another participant. In contrast, participants in the Disguised-Act-on-Other condition were less willing to accept the instruction that the learning phase presented to them in Problem 2 was their own and accurately identified that it belong to another participant.

General Discussion

The central issues concerning this study were to understand the effects on transferability of control performance and on self insight, when the learning experiences of a control task were limited, and when they were diverse. These issues set two theoretical approaches apart. Studies defending the involvement of implicit processing in learning complex rule systems (e.g., Berry, 1991; Buchner et al, 1995) predict that the diversity of learning experiences is inversely related to control performance, whereas studies examining the effects of goal-directedness on learning (e.g., Burns & Vollmeyer, 2002; Sweller, 1988) predict that constraining the learning experiences adversely affects control performance.

The results from Experiment 1 showed that when the transfer control task was identical in structure but perceptually dissimilar to the initial problem, and when the format of learning phases in each problem differed (Procedural-based vs. Observation-based), there was negative transfer of control performance and structural knowledge for the limited learning condition and positive transfer for the diverse learning condition. The same result was found in Experiment 2 when the structure and learning format of the problems were identical as well as perceptually identical (Act-on-Self, Act-on-Other). The evidence failed to support Buchner et al's (1995) prediction that the diversity of learning is inversely related to control performance. However, although consistent with evidence from studies of goal-specificity showing that constraining the learning experiences adversely affects control performance (e.g., Burns & Vollmeyer, 2002), neither position predict a negative transfer effect of control performance.

In addition, Experiment 2 eliminated the diversity of learning experiences as a potential explanation for the negative transfer effects found in 'self' experience in Experiment 1. Instead there was evidence to suggest that for the Disguised-Act-on-Self positive transfer was found despite the fact that they were re-exposed to their prior learning experiences. This result is all the more remarkable given that the only difference between this condition and the Act-on-Self condition was the belief in the origin of the learning phase presented in Problem 2. The findings from Experiment 2 clearly show that the perception of the learning phase affects the learning and inductive reasoning processes which are engaged.

Unnecessary Dichotomies?

A number of dichotomies (e.g., intentional vs. unintentional, NSG vs. SG, novice vs. skilled, rule vs. instance based learning, procedural vs. declarative) dominate research in problem solving. In the study of control tasks, two of the most imposing are the distinction between acquisition of knowledge through observation-based learning and action (or procedural)-based learning, and the distinction between implicit and explicit learning. They are also usually aligned with each other; procedural processes are synonymous with implicit learning, and likewise observational learning is described as invoking declarative knowledge that is generated by explicit learning. The first obvious problem with one of these distinctions is that although control tasks involve trial-by-trial learning and the interaction with a system, they are not incidental learning environments. From the outset of each control task that has been studied participants are informed that there is a rule that underlies the system and it is their objective to find it. Therefore, Berry and Broadbent's (1998) description of control tasks as proceduralized and incidental is inaccurate (Buchner et al 1995). The second problem is that the dichotomies are informed by the argument that in order to be dissociable the processes must be computationally incompatible with each other, but this unnecessarily limits the categorization of phenomena, and leaves much evidence out of this simple exclusive disjunctive category membership (e.g., Buchner, et al, 1995; Burns & Vollmeyer, 2002; Squire & Frambach; Vollmeyer, et al, 1996). Finally, the distinctions may be confounded by a simpler division which is bounded to a single concept: difficulty. That is to say, the unreliability in demonstrating dissociations between self report and control performance measures (e.g., Burns & Vollmeyer, 2002; Geddes & Stevenson, 1997; Squire & Frambach, 1990; Vollmeyer, et al, 1996), which is typically used to identify knowledge that is representative of separate learning systems may simply be because the difficulty of the measures is not always equated.

Berry and Broadbent (1987, 1988) suggested that input-output relations can be salient or non-salient and offer this distinction to account for discrepancies in the findings reported.

Although they do not operationally define saliency, they imply that saliency is the degree of transparency of the input-output relation, and when the relations are salient performance on direct and indirect measures is correlated because people bring their conscious knowledge to bear in controlling and understanding the control system. Berry (1991) examined the distinction between salient and non-salient input-output relations under conditions in which observation-based learning vs. procedural-was contrasted. Berry found that control performance was poorer for yoked-observers in non-salient conditions compared to the performance of the action-based learners that they were yoked to. However, in salient conditions positive transfer was found from observation-based learning to procedural-based testing. Berry claimed that this was consistent with Berry and Broadbent's claim that salient input-output relations are learnt explicitly and so there was no conflict between learning and test because the process invoked each time was explicit. However, these findings are entirely consistent with the proposal that the ease of transferability of knowledge is not based on whether or not the processes invoked are compatible, but is based on the degree of difficult of the input-output relations, and salient input-output relations are simpler than non-salient ones.

The data from this study show that negative and positive transfer of knowledge occurs independently of whether the learning format is observation-based or procedural-based. This is consistent with evidence from studies directly contrasting performance in control tasks in which learning is observation based and procedural-based (Osman & Heyes, 2005), and shows that there are no differences in performance as a result of the learning format. In addition, in the present study participants were shown to have access to information gained during learning, which allowed them to make accurate responses to awareness tests. Taken together, the evidence strongly suggests that there are no grounds for implicating implicit processes in the learning or test phases of control tasks, and that drawing a distinction between the functional properties underlying learning in observation-based and procedural-based learning formats is problematic.

Conclusions

The finding from this study demonstrates that participants were able to accurately identify their own learning experiences in a complex dynamic control task, suggesting that contrary to numerous studies, people are aware of the learning process they are engaging whilst problem solving. In addition, the findings also revealed that there was no difference in control performance when learning to solve a control task under an observation-based condition compared to an equivalent action-based version.

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Figure Captions.

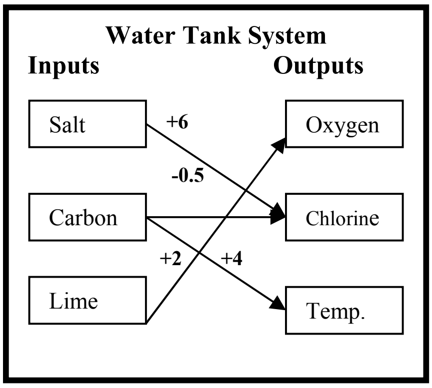
Figure 1. Water tank system with inputs (salt, carbon, lime) and outputs (oxygenation, chlorine concentration, temperature).

Figure 2. Diagram of structure of Experiment 1.

Figure 3. Mean Error scores (±SE) at Control Test 1 and Control Test 1 for each condition in Experiment 1

Figure 4. Mean Error scores (±SE) at Control Test 1 and Control Test 1 for each condition in Experiment 2

Figure 1.



Water Tank System
Inputs
Outputs
Salt
Carbon
Lime
Oxygen
Chlorine
Temp.
+6
-0.5
+2
+4

Figure 2.

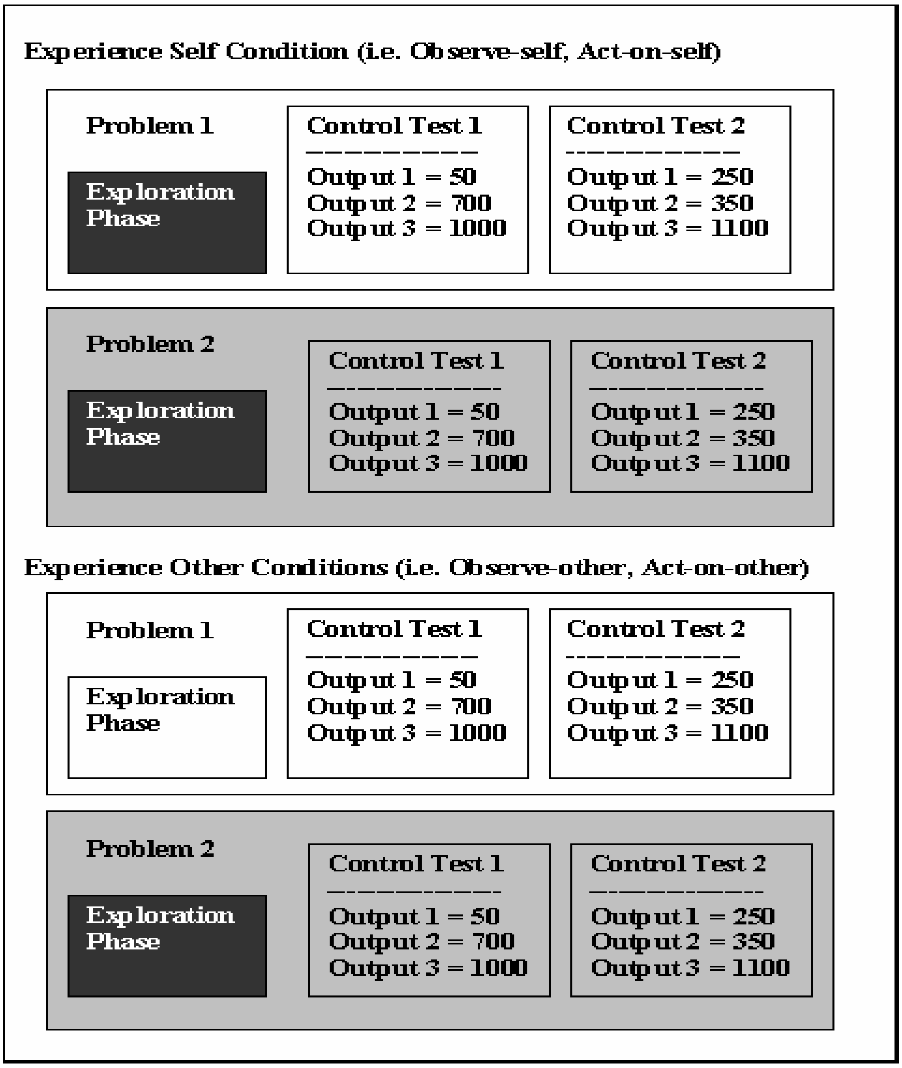

Experience Self Condition (i.e. Observe-self, Act-on-self)
Problem 1
Exploration Phase
Control Test 1
Output 1 = 50
Output 2 = 700
Output 3 = 1000
Control Test 2
Output 1 = 250
Output 2 = 350
Output 3 = 1100
Problem 2
Exploration Phase
Control Test 1
Output 1 = 50
Output 2 = 700
Output 3 = 1000
Control Test 2
Output 1 = 250
Output 2 = 350
Output 3 = 1100
Experience Other Conditions (i.e. Observe-other, Act-on-other)
Problem 1
Exploration Phase
Control Test 1
Output 1 = 50
Output 2 = 700
Output 3 = 1000
Control Test 2
Output 1 = 250
Output 2 = 350
Output 3 = 1100
Problem 2
Exploration Phase
Control Test 1
Output 1 = 50
Output 2 = 700
Output 3 = 1000
Control Test 2
Output 1 = 250
Output 2 = 350
Output 3 = 1100

Figure 3.

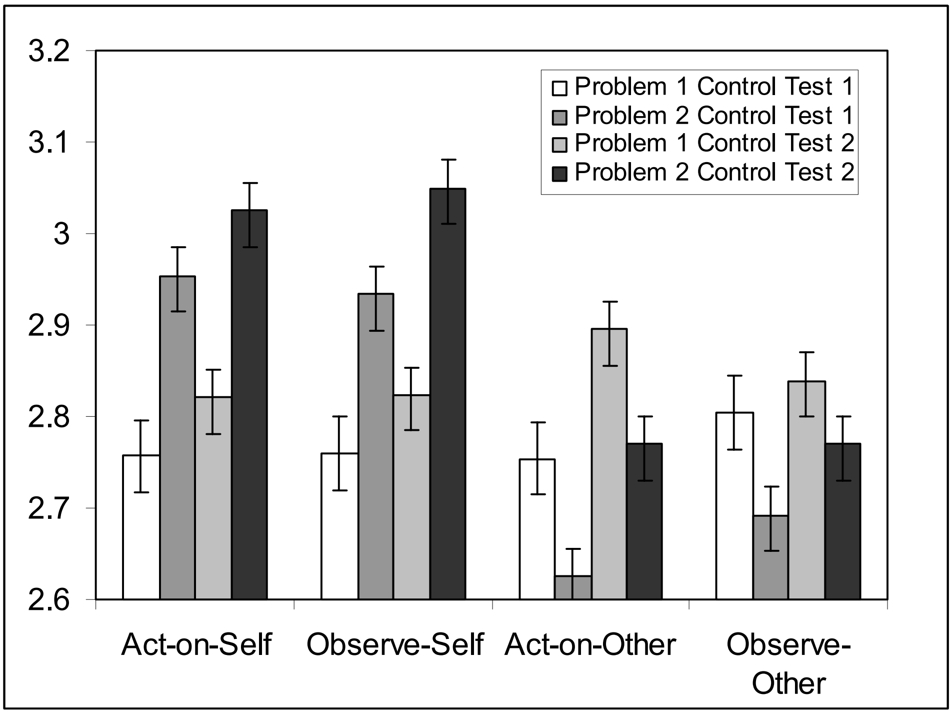

3.2
3.1
3
2.9
2.8
2.7
2.6
Problem 1 Control Test 1
Problem 2 Control Test 1
Problem 1 Control Test 2
Problem 2 Control Test 2
Act-on-Self
Observe-Self
Act-on-Other
Observe-Other

Figure 4.

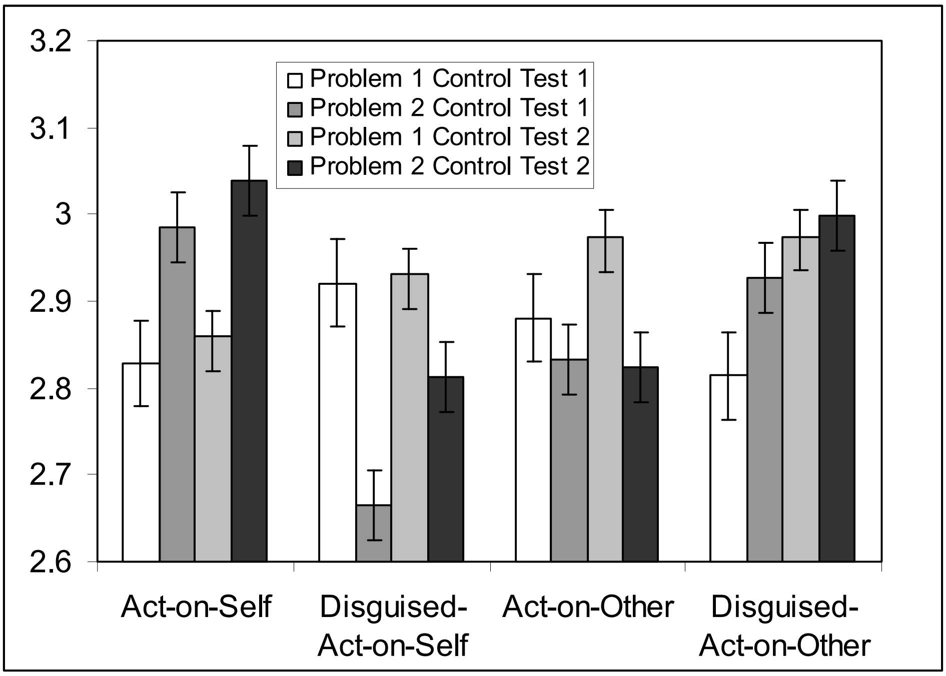

3.2
3.1
3
2.9
2.8
2.7
2.6
Problem 1 Control Test 1
Problem 2 Control Test 1
Problem 1 Control Test 2
Problem 2 Control Test 2
Act-on-Self
Disguised-Act-on-Self
Act-on-Other
Disguised-Act-on-Other

Table 1: Proportion of accurate responses to posttest recognition question

Condition	Experiment 1	
	Self	Other
Observation	92	75
Action	67	83
	Experiment 2	
	Self	Other
Disguised	33	75
Unconcealed	75	83