Educational Strategy and Cognitive Change: From Prolog to Stat Play

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In 1986 Cumming and Abbott investigated how a friendly version of the logic programming language Prolog could be used in the classroom. They assessed educational outcomes, especially as influenced by the design of the learners’ activities. In our current StatPlay research we are developing microworlds that provide illustrations and simulations intended to help learners achieve cognitive change and good understanding of basic concepts of statistics. Ten years on the hardware and software possibilities have advanced greatly, but our focus on learning activities and cognitive outcomes has endured.

In this paper we summarise the issues raised in Cumming and Abbott (1986) and discuss how these compare with the issues addressed in our current research (Cumming, Thomason, & Zangari, 1995). The computer tools being studied have changed enormously, but the focus on educational aspects has been maintained.

The Picture in 1986

In 1986 Logo was a big issue. Australia had helped pioneer widespread use of Logo by children in classrooms, partly as a reaction against the rigidity of drill-and-practice. Although there was little evidence of transfer from Logo experience to gains in higher cognitive abilities, such as reasoning and planning, Papert’s ideas were influential and there were widespread expectations of such gains. Also, the use of Logo was consistent with preference for a constructivist view of learning: children should have scope for initiative and expression of their ideas in computational form.

Among Logo advocates there was debate as to whether children should start with single commands of turtle graphics and build up to using procedures, or should initially be given whole, functioning procedures and only later look inside and investigate individual commands. This was the bottom-up (commands first) versus top-down (procedures first) issue.

Many felt that simply giving children access to the powerful and friendly expressiveness of Logo should suffice. Classroom experience, however, emphasised the value of giving children structured tasks, at least at first, and lots of support and advice. The laissez-faire view—simply make the tools available and watch the minds blossom—arose from a misreading of Papert (1980). Papert did emphasise that the child must be in control, but he also insisted that this approach ‘does not mean spontaneous, free-form classrooms or simply “leaving the child alone.” It means supporting children as they build their own intellectual structures...’ (pp. 31-32)

The La Trobe Prolog project

Following the pioneering work of Ennals in London, we investigated the value of using the logic programming language Prolog in the classroom. Logo was a procedural and functional language deriving from the Artificial Intelligence (AI) language LISP, whereas Prolog was a declarative AI language. Working with Jonathan Briggs in London we developed MITSI, a friendly version of Prolog for the classroom, and set out to study whether it had educational value. MITSI allowed children to state facts and relationships, and to define general rules. They could build and work with simple databases, have the computer carry out reasoning and give explanations for its answers, and construct small expert systems.

There was a strong parallel with Logo work, and we too grappled with curriculum organisation (top-down or bottom-up?) and the issue of learner freedom and control.

Working in local schools over several years we refined the MITSI language, and developed MITSI programs, worksheets and activities that teachers judged to be effective. We worked with Year 5 to Year 9 students and conducted a number of experiments on learning outcomes. MITSI was renamed ‘K-Log’ and, together with our programs and activities, was published (Cumming, Briggs, & Abbott, 1993). Experimental results were
reported in a number of papers appearing between 1985 and 1990. We presented evidence that working with Prolog can give educational gains that generalise to higher abilities, including reasoning and reading comprehension.

The 1986 AEC paper

The title of Cumming and Abbott (1986) was 'It's the educational strategy that matters, even if the language is Prolog'. Educational strategy referred to the two issues, or dimensions, mentioned above: top-down or bottom-up curriculum organisation, and structured or free learning activities. These defined a two-dimensional space, with any particular curriculum falling at some point in this space. We noted that these dimensions were relevant not only to Logo and Prolog but generally in education: approaches to teaching maths, or poetry, or biology could be discussed in terms of where they fell on these two dimensions.

We discussed the two dimensions and, with some trepidation, mapped the approaches of a number of well-known Logo writers into the space. For example we suggested that the very successful book by McDougall, Adams and Adams (1982) adopted an approach somewhat on the bottom-up side of centre on the first dimension, and spanning from the structured end of the second dimension part-way towards the free end.

We gave our MITSI learners printed worksheets that were at first very detailed and specific, then moved to encourage students to make their own extensions and variations, then to develop their own projects. Our preference for highly-structured activities at first was strongly supported by the teachers with whom we worked, and seemed to us to be essential for good engagement and learning. It did, however, fly in the face of the then-received view that learner freedom should be maximised at all times.

We took an experimental approach to the top-down versus bottom-up dimension. For six months one grade 5 class and one grade 6 class worked twice a week at a top-down curriculum, while a second class at each of grade 5 and grade 6 worked at a bottom-up curriculum. Then all children completed the same battery of written and computer tests. The overall results were positive, and teachers spoke enthusiastically of use of MITSI across the curriculum, and enhanced general skills.

In terms of the children's ability to understand and use the logic programming language MITSI we found that the top-down curriculum was considerably more effective than the bottom-up approach. The top-down children had a wider range of skills in using the language, and gained higher scores on a range of tasks requiring use of MITSI. In other words it is best to start working with whole programs, then to look inside these and modify them, then finally to build your own. This is more effective than the traditional approach, and the one most commonly used with Logo, of starting by learning to write single statements in the language, then working up to building small programs and using pre-existing programs.

Our fundamental argument was that questions like 'Is Logo (or Prolog) useful for children?', which were commonly debated then, are much too broad. We should rather ask about how a language, or any other tool, can best be used in education, and what particular educational gains it can give. On this issue ten years has seen progress: educational strategies and outcomes are more likely to receive detailed assessment now than in the early days of educational computing.

Ten Years on: The StatPlay Project

The starting points for our current work were a desire to find how to teach basic statistical ideas more successfully, and a belief that computer tools might provide the means. We briefly describe the problem, a promising approach to similar problems in physics, and the rationale adopted for our software StatPlay.

Statistical misconceptions

There is clear evidence that many people, including some researchers, have serious and persisting misconceptions about fundamental aspects of probability and statistics. Even successful completion of statistics courses does not guarantee that misconceptions will be overcome. Misconceptions relate to many important ideas including statistical significance, conditional probabilities and statistical power. Learners need cognitive change—a change to a more accurate conceptualisa-
Law of Small Numbers.

Naive physics and wrong. For example, many people reported evidence that it was effective in expectations that accord with naive confronted mistaken beliefs.

A simple example is 'The Law of Small Numbers', which states that we overestimate the extent to which a small sample is likely to tell us accurately about the population from which it came. In other words we are much too inclined to leap to conclusions on the basis of little evidence. Know a red-headed person who is hot-tempered? Meet another? Find a third, and your hunch that red-heads are volatile becomes a firmly held belief!

The Law of Small Numbers—it should be called the 'Fallacy of Small Numbers'-has more serious consequences when it leads a researcher to believe that a suggestive result in one experiment virtually proves that a repeat of the experiment would give the same outcome, and therefore that the result is established fact. There is clear evidence that researchers are often mistaken in this way.

We wondered whether computer-based illustrations or simulations of sampling variability might be sufficiently dramatic to help people achieve cognitive change and overcome the illusions of the Law of Small Numbers.

Naive physics

Naive physics refers to intuitive beliefs people use to guide their expectations about everyday events. Some naive physics beliefs are widespread, persistent, and wrong. For example, many people believe that a ball flying around on a string will take a curved path after the string breaks. Traditional education diminishes the influence of naive beliefs, but even physics graduates often have everyday expectations that accord with naive physics.

There have been several attempts to help students overcome naive physics beliefs by working with computer-based microworlds. For example White (1993) developed the ThinkerTools software and reported evidence that it was effective in helping 11-12 year olds develop accurate physics concepts. Learners undertook modelling and game-like activities about forces and moving objects; they formulated and tested hypotheses and confronted mistaken beliefs.

An important feature of the software was its use of multiple representations: an animation of an accelerating ball might be accompanied by a vector representation of force and a graph of the velocity-time relation.

White expressed several conclusions succinctly: 'Employ manipulable, linked representations for key abstractions. ... Make the phenomena easy to see and interpret.' (pp. 49-50)

From the work of White and others our conclusions are:

- The representations presented to students must be chosen carefully to present the target issues dramatically.
- Multiple representations yoked together offer a powerful strategy to bridge between concrete events and the symbolic representations of an academic discipline.
- Learners need scope for initiative, but also guidance, and activities with structure.
- Transfer of understanding to real world situations requires the use of learning activities designed specifically to achieve this goal.

Naive statistics and StatPlay

By analogy with naive physics we use the term 'naive statistics' for everyday beliefs about probability and statistics (Thomason, Cumming, & Zangari, 1994). The Law of Small Numbers is one example of a severe misconception within naive statistics.

The rationale for development of our software StatPlay is that the conclusions above can guide the design of computer-based illustrations and simulations that can be used to help learners overcome naive statistics beliefs and gain good understanding of fundamental concepts. In particular they should gain a good understanding of the extent of sampling variability and thus avoid the Law of Small Numbers.

StatPlay in outline

StatPlay is being developed in Visual C++ under Windows. There are currently 5 microworlds, or 'playgrounds':
- The Discrete Dataset Playground (see Figure 1) presents data as a list of numbers, an ordered list of numbers, a frequency histogram and a dot plot. These four representations all appear on the screen and are dynamically linked. Data points are easily added or removed. Percentiles, z-scores and a range of descriptive statistics can be shown.
- The Continuous Distribution Playground allows the user to explore normal or other distributions, including distributions of any shape, drawn freehand. Numeric values, e.g. of mean, standard deviation, skew and tail probability are shown. Dragging handles causes the display to change smoothly; the distribution 'feels plastic under your mouse fingers'. There is a game to sharpen intuitions about mean and standard deviation.
- The Sampling Playground is the first part of our attack on the Law of Small Numbers. A population distribution is shown in the upper panel of the screen (see Figures 2 and 3), and some representation of a number of samples taken from the population is shown below. The extent of variation from sample to sample can be seen strikingly, in several ways.
- The Confidence Interval Playground shows the confidence interval for the user's own dataset, in the context of a number of samples from a hypothesised population.
- The Hypothesis Testing Playground combines features from earlier playgrounds and gives the basis for building intuitions about inferences from a sample to a hypothesised population.

StatPlay in use

StatPlay is aimed at students in Years 11 and 12, and the first years of university. It has been used by more than 1000 psychology students at La Trobe University and the University of Melbourne. The response by students and their tutors has been very positive. In two initial experiments we have assessed students’ intuitions about the extent of sampling variability before and after working with StatPlay, and in comparison with a more traditional approach. The results indicate that learning activities based on StatPlay can indeed be effective.
Making concepts concrete

One key feature of learning environments is their presentation of simple concrete occurrences, for example the collision and deflection of a ball hitting a wall at an angle. The work of White, and many others, is based on such examples. Many fundamental statistical ideas, however, cannot be fully illustrated by any single example: they involve properties of whole sets of occurrences. Moreover these properties are uncertain or variable. For example, the variation from sample to sample is such a property. If we simply take a few samples we may by chance get an unusually small or large amount of sample-to-sample variability. (And the Law of Small Numbers itself would lead a student to believe, erroneously, that those few samples are completely typical!)

On the other hand we could present the sampling distribution that summarises the amount of variability that arises if we take an infinite number of samples. Doing so, however, loses the simplicity and concreteness of the single sample—the very strength of using a microworld!

Our solution is to provide the user with total control over sampling. First you can take one sample, step by step, then a few, then a large number. At each stage you can inspect individual samples (Figure 2), or a summary (Figure 3). If you then ask for an infinite number of samples, an animation takes you to the overall summary sampling distribution.

The effectiveness of this strategy has yet to be assessed, but user response is positive. If effective, a similar approach could be taken to presenting a wide range of concepts in probability and statistics. Consider for example even the simple case of illustrating that the probability of a Head from a coin toss is 0.5. First would come a single toss, then a series, then a longer series, and finally an overall summary. At any stage you could inspect any part of the sequence, thus bridging between any single toss, the general pattern, and the overall summary. Such flexibility is vital because appreciation of true randomness is known to be extremely problematic.

Our strategy for bridging from the single case to the general overview may have wider applicability, and may prove a useful expansion of the possibilities available to microworld designers.

From Prolog To StatPlay

In the Prolog project we took a promising tool that had just appeared, built a friendly version for use in the classroom, developed learning activities and materials in consultation with teachers, and assessed educational outcomes. We were particularly interested in assessing different curriculum approaches (top-down or bottom-up), and the transfer to higher cognitive abilities. We drew from contemporary debates in educational computing and attempted to find evidence that would contribute to these debates.

Our starting point was the arrival of logic programming, a new computing possibility. But more than a computer tool is needed: our emphasis was on finding learning activities that could exploit the tool, and then on assessing the educational outcomes.

In the StatPlay project, by contrast, our starting point was a persistent educational problem: traditional teaching approaches seem unable to overcome naive misconceptions. We drew on contemporary educational computing, as well as design principles for computer interfaces, to develop playgrounds and learning activities intended to help learners surmount their naive statistics misconceptions. Our development of a strategy for bridging from the concrete instance to the general overview may have wider applicability in microworld design.

Computers are now more powerful, computer tools richer and easier to use, and our educational goals are more ambitious. However the focus on learners and what they do, and on the resulting cognitive changes, endures. Long may it be so!

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REFERENCES


