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Can learning a programming language affect metacognitive beliefs and science beliefs of junior high school students?

William J. Chivers and David H. McKinnon

Abstract—The effects of learning the computer programming language Logo on metacognition has been the subject of much educational research. The effect of Logo on the restructuring of science beliefs of junior high school students by the transfer of higher order skills from one domain to another has received less attention. This paper reports the results of an attempt to alter students’ expected transmissive metacognitive beliefs by teaching them Logo so that they would, perhaps, be more willing to restructure their science beliefs.

This research finds strong evidence that a science teaching method derived from the constructivist model of learning combined with a Logo teaching environment is successful in persuading students to restructure their science beliefs. The effects of Logo on metacognitive beliefs and higher order skill transfer, however, are inconclusive. Directions for future research in this area are suggested.

I. INTRODUCTION

Students entering high school do so with well-developed and firmly held beliefs with which they explain and predict phenomena within their worlds [1], [12], [14], [15], [22], [28]. This is particularly true in the subject of science, as children have been exposed to the natural world all of their lives and continuously and tacitly build and test beliefs and models about the natural phenomena to which they have been exposed.

These beliefs are frequently at variance with the views currently accepted by the scientific community. One example of such a belief is the explanation that wind is caused by trees “flapping their leaves”. Here, the observed correlation of wind and flapping leaves has been interpreted by the student (age 13) to be the reverse of the cause and effect direction that “science” would employ to explain, at least in part, the phenomenon of wind.

The secondary school science teacher faces the task of replacing the students’ naive science beliefs with the currently accepted scientific beliefs. Most science teachers, however, attempt to do this without being aware of the current state of the students’ beliefs [1], [6], [12], [14], [28].

A result of being unaware of their students’ beliefs is the failure of teachers to realise the effects that can be produced as the currently accepted science belief is presented and interacts with the students’ personally held beliefs. In one interactional form, the currently accepted science belief is mixed with the students’ model to produce a hybrid. For example, the condensation produced on the outside of a glass of cold water may be explained by the student as “the water inside the container diffusing through the glass” after a lesson on diffusion. Various other amalgams are produced by these interactions of personal belief and science belief [13], [14]. Because teachers are generally unaware of the students’ beliefs and the hybrid beliefs resulting from their exposure to the teacher’s science, secondary schools have generally been unsuccessful in replacing students’ science beliefs with those of the scientific community.

The constructivist model of knowledge and learning offers an explanation for the existence of a diversity of students’ scientific beliefs. It also leads to the possibility of fashioning an alternative teaching sequence that encourages students to reconstruct their existing science beliefs in the direction of the currently accepted scientific beliefs. Such a teaching sequence has the potential to be more successful than the traditional transmissive approach to science teaching in persuading students to reconstruct their beliefs in the direction of the currently held beliefs of the scientific community [12], [14]; [15], [17], [28].

The product of a constructivist teaching sequence in science is not necessarily students who have adopted the currently accepted science beliefs. Rather, the degree of success is judged by the extent to which students have shifted their current beliefs towards the currently accepted science beliefs. Also recognised is the possibility that not all students are able to arrive at this latter point given their stages of intellectual development.

Despite the promise of constructivist approaches to science teaching, the teaching strategy derived from this model of learning may be inhibited by the students’ metacognitive beliefs. Constructivist science teaching sequences require significant mental effort on the part of the students, and existing transmissive metacognitive beliefs of the students may impede progress in science. Gunstone [15] found that the majority of students entering high school believe that their role in learning is a passive one. Students do not appear to be willing to expend the mental effort necessary for the replacement of their current scientific beliefs. The beliefs of junior high school students found by Gunstone are listed below.

1) The student’s role is a passive one and students bear no responsibility for their own learning. It is the teacher’s role to teach, and the student’s role to absorb information.

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2) Each lesson is separate with few links with other lessons.
3) Many students believe that they will never understand science: to do so requires intelligence and memory beyond their own, therefore to try is futile.
4) The amount of content covered is of paramount importance, hence to spend time trying to understand one component is a waste of time.
5) Thinking is not a productive use of time. "Work" involves writing notes or producing other concrete outcomes.

The constructivist approach may be more successful if students held different metacognitive beliefs than those found by Gunstone: that is, if students were willing to accept the importance of their role in their own learning.

Students' existing metacognitive beliefs may be challenged if they can successfully learn a new, complex and highly motivating skill in an environment of self-directed learning. Various researchers claim that the teaching environment created by learning the computer programming language Logo makes possible successful, self-directed learning that is highly motivating for students [9], [20], [23], [24]. In this research the Logo language is used in an attempt to challenge the students' pre-existing transmissive metacognitive beliefs, thus facilitating the constructivist science teaching approach.

The use of a different learning domain to challenge the students' metacognitive beliefs assumes that any reconstruction of metacognitive beliefs in this domain will be transferred to the domain of science. Many attempts to measure the transfer of higher order skills developed during computer programming to other domains have been made. The results are mixed. Researchers such as [10], [8], [7], [20] found evidence of such a transfer. Other researchers such as [26] and [19] found no evidence of transfer. These latter researchers tended to use very little instruction in Logo, no explicit fostering of the transfer of higher order skills, a failure to look for appropriate types of transfer and, in some cases, employed a questionable methodology.

Taking into account these findings and possible reasons for the failure to find evidence of transfer, a strategy to foster the transfer of metacognitive beliefs was developed. This involved:

1) the mindful engagement of the students in their learning of Logo,
2) the awareness of the students of the processes of their own learning,
3) the overt and explicit references by the teacher to the similarities between learning in the Logo classroom and learning in the constructivist science classroom,
4) a long period of intervention, and
5) an initial measured amount of didactic instruction in Logo.

During learning in the Logo classroom the students were encouraged to discuss their metacognitive beliefs in an attempt by the researcher to encourage the transfer of any altered metacognitive beliefs to the domain of science.

The purpose of this paper is fourfold. First, the interventions involving the constructivist teaching approach in science is described. Second, the Logo component is described. Third, the results obtained from comparing the students' science beliefs over the course of one year are presented. Fourth, a discussion of the interesting results obtained is presented and suggestions made for further research in this area.

II. Method

A. Participants

Three equivalent groups of year seven students (N=85) were the subjects of this study lasting for one school year. The students were from a working class area in Sydney, Australia and were enrolled in a state high-school. For the purposes of this research the three intact groups (Constructivist Group (CG), Logo/Constructivist Group (LCG), and Control (CON)) were assigned to three treatments:

Two groups were taught science using the constructivist method derived from the research presented above. One of these groups (CG) was taught science for eight periods per fortnight. The Logo/constructivist group (LCG) was taught science using the same constructivist teaching approach for five periods per fortnight. In the remaining three periods the students were encouraged to explore the language Logo after a few weeks of more didactic instruction. The third group (CON) was taught science in the traditional didactic manner for eight periods per fortnight and acted as a control.

B. Instruments

Five variants of the Tapping Students' Science Beliefs (TSSB) instrument [1], [11] were used as the end of topic tests during the year. The TSSB is designed to measure the extent to which students have replaced their own science beliefs with those currently held by the science community.

The Learning Process Questionnaire (LPQ) instrument [3], [4] was used three times in the year. The LPQ is a self-rating questionnaire designed to measure a student's approach to learning. Movement in the students' approaches from a surface approach to a deep (intrinsically motivated) approach would provide evidence of a change in the students' metacognitive approach.

Students' reading ages (Gapadol) were obtained from school records as a way of ascertaining the extent to which the three classes were 'equivalent'. Unfortunately, or perhaps fortunately, the class assigned at random to the LOGO/constructivist treatment had a significantly lower mean reading age.

Interviews were conducted with selected students at the beginning and end of the treatment, and were designed primarily to look for changes in their metacognitive beliefs and approaches to learning.

C. Analysis of quantitative data

An analysis of variance procedure with repeated measures on the occasion of testing was employed to investigate changes in students' science beliefs and their learning approaches over the course of the year. The nested design employed fully controlled for the constructivist approach and to a lesser extent the effect of Logo. This allowed the impact of the Logo treatment to be investigated.
Reading age
CG > LCG despite random assignment of subjects

Science beliefs
LCG and CG > CON on all tests with difference increasing
LCG = CG on all tests except test 5
LCG > CG on test 5

Approach to learning
Scores of LCG = CG = CON on all occasions
Trends of LCG = CG = CON throughout the treatment

Interviews
No passive, transmissive beliefs found
Metacognitive beliefs were unchanged through the year
The students do not actively think about their role

Key
CG: Constructivist group
LCG: Logo constructivist group
CON: Control group

TABLE I
SUMMARY OF FINDINGS

III. RESULTS
The findings of the research relevant to this paper are summarized in Table I. The major points are:

- Despite the random assignment of students to the groups, the Logo/constructivist group had a significantly lower reading age than the other two groups, which were equivalent.
- No difference was found in the science beliefs of the two constructivist groups (Logo and non-Logo) until the last test, on which occasion the mean score for the Logo/constructivist group was significantly higher than the mean score for the constructivist group. Significant differences between the science beliefs of the constructivist groups (Logo and non-Logo) and the control group were found over the five tests.
- No differences in learning approach were found among the three groups on any of the occasions, nor do the trends in test performance of the three groups differ.
- No transmissive metacognitive beliefs as found by [15] were found. The students consistently believed that theirs was an active role, that the responsibility for learning lay with them, and that they would understand science if they tried.

A. Reading age
The students’ reading ages were measured by the Gapadol reading age test. The multiple comparison procedure used, the Scheffé test, found the groups significantly different at the 0.050 level. The Logo/constructivist group had a significantly lower reading age than the other two groups, which were equivalent, despite the apparently random assignment of students to these groups.

In addition, all teachers (of other subjects) reported that Logo group was a far more difficult class due to the personalities and individual problems in the group.

B. Science beliefs
The TSSB mean scores as a percentage of the maximum possible score on each test are graphed in Figure 1.

The TSSB test results indicate significant differences among the three groups over the five TSSB tests. The constructivist groups (Logo and non-Logo) performed at a significantly higher level than did the control group in all of the tests. The two constructivist groups were not significantly different until the last test, where the mean score for the Logo/constructivist group was significantly greater than the mean score for the constructivist group. This may indicate that the measurable effects of the Logo programming language on the reconstruction of the science beliefs of the students in the Logo/constructivist group became apparent only after several months of the treatment.

The Logo/constructivist group out-performed the constructivist group on the final test despite the fact that the Logo/constructivist group had a significantly lower mean reading age than the constructivist group. This unexpected difference (the reading age) between the two constructivist groups may have significance for this research.

C. Approach to learning
No significant differences in learning approach are found between the three groups, nor do the trends in LPQ test performance of the three groups differ over time. The approach to learning of the three groups was very similar at the beginning of the year, and evolved during the year in very similar ways. The most significant finding of the analysis of learning approach was that all groups increased in their surface approaches to learning and decreased in their deep approaches. That is, over their first year in secondary school, these students appeared to increasingly adopt an approach that employed rote memorisation of material for the purposes of testing rather than an approach of integrating the new knowledge within existing frameworks. These results will be reported in detail elsewhere.

If the use of the Logo programming language had affected the students’ metacognitive awareness or beliefs, then it was
expected that these differences would have been reflected in differences between the learning approaches of three groups as measured by the LPQ. An increase in metacognitive awareness would have been indicated by an increase in the deep and/or achieving approaches to learning of the students, and a decrease in the surface approach [4]. Such differences would have been used as evidence that the metacognitive awareness of the groups was changing as an effect of the treatment, either the constructivist approach or the use of Logo or both. The fact that these changes were not found is evidence that the metacognitive awareness and beliefs of the groups did not change due to the intervention as measured by the LPQ.

D. Metacognitive beliefs

The fact that no transmissive metacognitive beliefs were found in the students in this research is significant, as the passive transmissive beliefs predicted by [15] were the reason that a Logo group was planned for the research. Although discussion of changes to the metacognitive beliefs of the students and the amount and type of transfer of these higher order skills from the domain of Logo to the domain of science is impeded because the anticipated beliefs of the students were not found, some interesting points can still be made about these findings.

IV. Discussion

The constructivist approach to science teaching used in this research appears to have been highly successful in encouraging the students to reconstruct their science beliefs in the direction of the beliefs currently held by the scientific community. The effect of Logo on the reconstruction of the science beliefs of the students in the Logo/constructivist group is not made clear by the findings of this research, however, for the four reasons listed below:

1) The metacognitive beliefs found in junior high school students by Gunstone [15], beliefs that could have impeded the constructivist approach in science, were not found in these students. These students started the treatment with metacognitive beliefs that were compatible with the constructivist approach in science.

2) No evidence of transfer is found. The Logo/constructivist group believed that they taught themselves in Logo but not in science classes (despite the efforts of the researcher to allow the students to develop explanations for phenomena themselves as part of the constructivist science teaching sequence), and this belief persisted throughout the treatment.

3) The LPQ data reveal no differences in learning approach between groups nor any differences in the trends in the scores of the three groups.

4) The Logo/constructivist group outperformed the constructivist group in the fifth and last TSSB test. This may indicate some effect due to Logo that is difficult to ascribe in this investigation.

While we cannot comment directly on the effect of Logo on the students’ metacognitive beliefs or on the transfer of these beliefs to science from these results, some points may be made about the effects of Logo and some directions for future research are indicated.

The equivalence of the two constructivist groups from the very first TSSB test and the superior performance of the Logo group on the last TSSB test should be further explored. The mean reading age of the Logo group was significantly lower than that of the other two groups, and this group was notorious within the school (amongst the teachers) as being a very difficult class to teach. Why was this disadvantaged group able to match and eventually out-perform the students in the constructivist group, a much easier class to teach and one which was well liked among the teachers?

Was Logo any advantage for these students? The only difference between these two groups was their experience with Logo. The performance of the Logo group in the TSSB tests appears to support the hypothesis that the use of Logo was an advantage, overcoming the disadvantages experienced by the group. This hypothesis is problematic because no evidence for it was found in this research: the advantage that the experience with Logo was expected to give the Logo group—that of reconstructed metacognitive beliefs that would not impede the constructivist approach—was not detected.

A second problem with this hypothesis is the fact that the two constructivist groups were equivalent from the first TSSB test, which was administered in the ninth week of the treatment. This is a problem because any changes to metacognitive beliefs as a result of successful learning in Logo and the transfer of these metacognitive beliefs to science would both be expected to take longer than a few weeks.

Researchers such as [19] and [26] who find no evidence of transfer of higher order skills typically used a short intervention, whereas researchers finding evidence of transfer, including [7], [8] and [10] used longer interventions. In addition, before higher order skills can be transferred, they must be developed, and it is very unlikely that any changes to the students’ metacognitive beliefs occurred in the first few weeks of experience with Logo as this time was taken up with the measured amount of didactic instruction in Logo before the students were allowed to choose their own projects and start their own explorations of Logo. Researchers such as [9] also cite time as important if metacognitive experiences are to occur in the Logo classroom. If Logo did give the Logo/constructivist group an advantage, it was not the advantage anticipated in this study.

An alternative explanation of the TSSB results is that the Logo environment established in the computer laboratory helped in classroom control of this difficult group during science classes. Perhaps the positive experience of the Logo lessons was transferred to the science classroom (with the same teacher—the researcher). The students were fascinated by Logo. This difficult and alienated group of students was transformed in the Logo classroom. The students came into the computer laboratory and eagerly continued with their projects, discussing them within their small groups and with students in other groups, showing each other their successes and failures, asking for ideas for more projects, showing the researcher things that they had discovered, and generally demonstrated that in an interesting, student-centred and non-threatening environment they were capable of significant achievements. Errors
were quickly recognised as a part of programming and a part of learning, and the students frequently dealt with them by asking other students for help rather than the researcher.

The Logo environment was chosen for this research because of its reported stimulation of intrinsic interest and “mindfulness” [2], [9], [16], [24], [25], and in doing this the Logo environment was very successful. When asked for help, the researcher followed the practice of [18], [8], [9] in guiding the student(s) to a discovery of the problem, rather than simply pointing to the error. In such an environment, according to [5] and [21], the students grow to like the teacher and are more readily influenced by such a teacher. It is possible that the students viewed the researcher as different to other teachers because of this positive experience in the Logo classroom and that this positive view of the researcher was transferred to the science classroom, assisting in the control of the group and therefore its learning in the science laboratory.

In response to the question “Do the lessons in Logo help you to learn science?” posed in the interviews the response “Logo helps in science because we like Logo” supports this suggestion. Students would often talk to the researcher enthusiastically about Logo in their science classes and in the playground. The researcher had far less difficulty with this class than did other teachers but nonetheless they could still be a difficult group. Significantly, perhaps, the constructivist group outperformed the Logo group in all subjects other than science.

Another possible explanation of the performance of the Logo group in the early TSSB tests is simply that the five periods of science per fortnight were sufficient for the constructivist teaching approach to be effective. The extra three periods that the constructivist group received may not have made a measurable difference, nor did the inherent problems of the Logo group which were overcome by the success of the constructivist approach. Certainly the constructivist teaching method did result in the students in both classes working in small groups discussing the subject matter and performing experiments, although this happened less in the Logo class than in the constructivist class.

V. CONCLUDING REMARKS

The constructivist teaching sequence developed from that described by [29], [28] was very successful in moving the science beliefs of the students towards the currently accepted beliefs of the scientific community. The effect of Logo is less clear. The hypothesis that experience with Logo will cause students to change their metacognitive beliefs and that these new metacognitive beliefs will facilitate the constructivist teaching sequence is not directly supported by this research.

The constructivist teaching sequence worked well with both groups from the start of the treatment, but the apparently positive effect of Logo on the reconstruction of science beliefs remains unexplained. The result of the last TSSB test may indicate that Logo provided some benefit. The experience of the researcher is that the environment created in the Logo classroom certainly appeared to have been beneficial to the students, who were interested, excited and generally on task in these classes far more than they were in other teachers’ classes.

VI. FURTHER RESEARCH

A. The metacognitive beliefs of junior high school students

The use of Logo in this investigation was planned because the metacognitive beliefs of year seven students were expected to be an impediment to the constructivist approach, which places the ultimate responsibility for learning with the learner. As discussed above, these beliefs were not found. Why is there a discrepancy between the results of this investigation and those of [15]? Do the metacognitive beliefs of year seven students vary from school to school, and if so what factors are affecting them? Why could the Logo group see that they were teaching themselves in Logo but could not see that this was the case in science (interview results)? How much do students think about and understand the processes at work in their classes and in their learning? The answers to these questions appear to be very important to successful education and should be the focus of future research.

B. The effect of Logo

The superior performance of the Logo group in the last TSSB test is tantalizing: why did such a disadvantaged group outperform the constructivist group in this test? Indeed, why did they perform as well as the constructivist group all through the treatment? Was there some effect due to their experience with Logo that was undetected by this research? The effect of the interactive, activity based, student-directed and non-threatening environment possible in the Logo classroom should be the basis of continuing research.

The effect that this environment had on the classroom dynamics of the Logo group strongly suggests that this learning environment was beneficial, and should perhaps be a model for all learning environments. It may be possible that higher order skills are developed in the Logo environment, and that these skills are indeed transferred to other domains perhaps by the high road transfer described by [27]. The existence of such transfer of higher order skills, the nature of such a transfer and the development of an instrument to detect such transfer could form the basis of future research.

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