Moments In The Process Of Coming To Know

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This paper reports on research which attempts to conceptualise, operationalise and document instances of meaningful learning in the secondary mathematics and science classroom, and the conditions under which this learning occurred. A "Linkage Criterion" for meaningful learning is proposed and applied to the data from 67 interviews of students reflecting on their classroom learning experiences. Instances of meaningful learning were few and comparatively impoverished where they occurred. The data suggests that the role of out-of-class experiences as classroom focussing mechanisms is a significant one. If teachers plan their instruction with the goal that students should acquire significant new knowledge in every lesson, our data suggests that this goal is achieved sufficiently rarely as to call it into question.

Classrooms are meant to be places in which learning is facilitated. It is reasonable to expect that this learning has some meaning for the student. Our goal is the creation of a learning environment in which students are not simply accumulating isolated facts and procedures, but are involved in integrating, or linking, new concepts and skills into an already existing conceptual framework. This form of interconnected knowing we refer to as *meaningful learning*. In this view, meaning is measured by the richness and complexity of these links. Using this image of linkages, the phrase "attaching meaning" takes on a very specific metaphorical character.

This paper reports on research which attempts to conceptualise, operationalise and document instances of meaningful learning in the secondary mathematics and science classroom, and the conditions under which this learning occurred. Such information could inform attempts to facilitate meaningful learning, and evaluate the effectiveness of teaching strategies designed to enhance or promote this form of learning. This paper is concerned only with the occurrence of meaningful learning and some of the characteristics of the classroom episodes with which it was associated.

Learning has been studied in many ways and in many settings. Recognition of the situated nature of learning has led to studies of workplace learning (for example, Lave, 1988). By contrast, learning has been studied through Teaching Experiments in clinical settings involving small groups of students (for example, Steffe, 1991). Classrooms are distinguished by being environments with the specific purpose of serving as sites for learning. Learning in classroom settings is no less situated than learning in other settings. This may seem an obvious assertion, but one consequence of the current enthusiasm for workplace learning could be an eroding of the status of the classroom as a setting for legitimate, meaningful mathematical activity. If the community is to continue to employ schools as the principal means by which young people are educated and enculturated into academic disciplines, then educational research must attend to the characteristics of the learning environments in such settings and to the processes by which learning occurs in classrooms. Many researchers have made the classroom the focus of their efforts (for example, Yackel & Cobb, 1993). There are certain characteristics of structure and purpose shared by all classrooms. Equally, each classroom presents a unique social setting, which facilitates and constrains the actions of all participants and the form of the consequent learning. Classroom research typically attempts to capture the characteristics of learning in one classroom in a form that will bear translation to other classrooms. This paper documents one attempt to characterise the form taken by this classroom learning.

Research Methodology

The research procedure we adopted was developed in an attempt to study learning in legitimate classroom sttings, while minimizing the need for researcher inference regarding student thought processes. To infer student thought processes and the significance of classroom events on the basis only of videotape data seems an unjustified extrapolation. Clarifying and corroborative data can be provided by the students themselves in interview situations, where their accounts of the significance of classroom events and their associated thought processes can be reconstructed with the assisting prompt of the classroom video record. More detail regarding the rationale for this research technique can be found elsewhere (Clarke, in press; Clarke & Kessel, 1995).

A total of thirty-three secondary maths and science classes were videotaped using two cameras. One camera was directed at the teacher, while the other camera was focussed on a group of about four students. The teacher's utterances were recorded through a radio microphone and a single microphone was used to record the conversations of all four students. The two video images were mixed to produce a composite picture in whch the students occupy most of the screen with the teacher image superimposed in a corner of the screen. This combined image was recorded onto video-8 tape using a compact videorecorder attached to a laptop computer. The researcher, seated at the rear of the classrom, was able to listen simultaneously to both student conversations and teacher utterances and recorded field notes onto a word processing document on the computer using *CVideo* software (Rochelle, 1992). The field notes can be "time-tagged" to corresponding events in the video record. The field notes enable the researcher to document impressions of significant classroom episodes and learning events as well as provide reference markers for the subsequent interviewing of student subjects.

Relating the interview to the video record

Students from the groups which had been videotaped were interviewed immediately after the lesson, a total of sixty-seven student interviews. The videotape record was used in the interview to stimulate student recall of classroom events. The use of the *CVideo* software enabled the researcher to locate within the field notes refernce to actions of the student which seemed to be of significance either to the researcher or to the student. Having found a particular item in the word document, the software could be used to very quickly find the corresponding moment on the video record. This was then played back and discussed. The audio record of the interview provided a third source of data, which in fact was the primary source of data for this paper. A more detailed account of the research methodology can be found in Clarke (in press) and Clarke and Kessell (1995).

Operationalising Meaningful Learning

In order to operationalise meaningful learning, we have generated a list of characteristic student actions, which we have employed as indicators that "meaningful learning" has occurred as a consequence of classroom experiences. These characteristics are set out below.

A Claim to New Knowledge: In order to substantiate a claim to have learned something meaningful, a student must, first of all, claim to have learned something new.

The Communication of New Knowledge: Having claimed to have learned something, a student should be able to articulate or demonstrate what it is they think they have learned, with some degree of clarity and accuracy. This elaborates their claim to have learned, but it does not justify classifying the learning as "meaningful"

The Demonstration of Interconnected Knowing: For the learning to be regarded as meaningful, there should be demonstrable links with an existing framework that the student already possesses. If there are no links (that is, the learning has the form of an isolated fact or procedure) we would argue that the student has not attached meaning to whatever it is that they have learned. Moreover, it is our suggestion that the greater the number of linkages which can be formed with the new knowledge, the greater chance there is that the new knowledge has meaning for the student. To meet the Linkage

Criterion for meaningful learning, the student must therefore articulate some form of relationship between the lesson's academic content and at least one of the following:

(i) the content of previous lessons in the same school subject
(ii) the content of other school subjects
(iii) future studies (in the same school subject or other subjects)
(iv) previous personal experiences
(v) subsequent uses to which the lesson's content might be put outside the classroom.

Interview Questions

A number of issues were discussed with the students at the conclusion of the lesson. This paper forms part of a broader study, so only interview questions designed to elicit information specific to the theme of this paper are documented below.

1. Student claim to new knowledge

Students were asked to summarise the content of the lesson. Sample questions included: *What was that lesson about? If someone were to ask what you learned in that lesson today what would you say? Was this something you knew before? Was there something which you did not know before this lesson, but which you would now claim to know?*

This question was designed to establish whether or not the student could articulate the primary content of the lesson; to establish a claim to have learned something new.

2. *Communication of new knowledge*

Sudents were asked to elaborate in more detail what it was they learned in the lesson. Sample questions include: *What was it that you learnt from this lesson? So could you complete this sentence "In this lesson I learned that..."*

3. *The Demonstration of Interconnected Knowing*

Further questions were asked to tap in to the connections the student made with prior learning and possible future use. Examples of these are: *Was this related to work you did last year? Can you imagine using anything that you learned in that lesson? Why would you want to know that?*

The interviews were transcribed and analysed for reference to these areas in the discussion between student and interviewer.

Levels Of Learning

The extent to which students made connections can provide insight into the meaningfulness of learning, which could be imagined along a continuum from a situation where the student learned an isolated fact or procedure to a situation where a rich and complex linkage with existing conceptual frameworks has occurred.

Meaningful learning could involve the elaboration or consolidation of an existing construct, or relinquishing a transitional construct in favour of a more correct or elaborate one. It could also involve the synthesis of constructs to form a new construct at higher level. For example, a student moves from knowing how to find the area of a square, a rectangle or a triangle as a procedural exercise to an understanding of area as a general concept.

Results And Discussion

Sixty-seven interviews with year seven, eight and nine students at an independent school in an outer eastern suburb of Melbourne were examined for the evidence of meaningful learning, as operationally defined above. The prime focus of this study was to document the presence and extent of meaningful learning. The following discussion provides examples from the data of situations along the continuum from isolated, non-meaningful learning to examples of learning where rich connections were articulated.

There were many instances in which students neither claimed that learning had taken place, or if they did, they were unable to elaborate what they had learned with enough clarity to have that claim substantiated. When a student did substantiate a claim to new knowledge, there were a very small number of instances in which the students made connections between their new learning and existing frameworks, in terms of the categories set out above.

The examples below are taken from interviews in which the student claimed to have learned something new. In selecting examples, we have attempted to illustrate instances of learning categorised according to "meaningfulness". Some students articulated isolated pieces of knowledge. Others demonstrated that they were struggling to find meaning but were not able to achieve it. Very few actually met our criterion for meaningful learning.

Non-meaningful learning

In this interview, Shona described how she tends to simply apply the most recent thing she has learned, regardless of its relevance to the task at hand:

S: If you try to do a fraction and you're trying to put it into lowest common denominator um, then I'll end up doing something different like the newest type of fraction that we've done and I work a different sum for it completely and I'll just go on to a different track like I'll be doing timesing the two fractions together instead of changing it to the lowest common deminator, so I'll do the wrong thing . . . Well I look at it and I think "Oh, well, if it's not right, I'll just do it anyway, just to, at least I've got answer down there and that might be right." So I just kind of hope. 'Cause I can remember how to do the newest ones, so that's the one that I usually do.

Shona's attitude to mathematics echoes the experience of students referred to by Schoenfeld (1992) who react to the arbitrariness of methods imposed on them by teachers and texts.

> Students may simply give up trying to make sense of the mathematics...they may come to believe that mathematics is not something they can make sense of, but rather something almost completely arbitrary (or at least whose meaningfulness is inaccessible to them) and which must thus be memorized without looking for meaning - if they can cope with it at all
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> (Schoenfeld, 1992, p. 343).

Students' inability to envisage any potential use for new knowledge or a procedure was a feature of several interviews relating to both mathematics and science classes. For example, Harry had just completed an experiment which served two purposes: to calculate his own lung capacity and learn a technique (displacement) for finding the volume of an irregular object. Harry was able to articulate what he learned, but unable to link this to previous lessons or to any other school subject and when asked if he could imagine using anything he learned in that lesson, the only possibility he could think of was if he were to become a teacher himself.

Struggling for meaningful learning

There was a sense with some students that they were trying to find connections, but were unable to do so. Shona, in a year 8 science class. had just done an experiment designed to measure the energy content of food. Students heated various items of food using a bunsen burner and measured the temperature increase of water in a test tube. She was not yet comfortable with the connection between the the amount of energy in the food and the rise in temperature of the water.

I: OK, unpack that one for me, if you had to explain it to somebody else, I mean, I don't know if you've got a younger brother or sister, a year 7 kid, somebody who peers in the window and they say "You guys are burning peanuts, that's really weird", how would you explain?

S: Um, well I'm burning the peanut to see, 'cause then all the steam and everything comes off the peanut, and comes off the water in the test tube and it makes the temperature of the test tube um, product, higher, and that way you find out how much energy's in it.

I: Did you understand?

S: I did understand how it was supposed to work out how much how much energy was in it, 'cause like you're just burning it and seeing how, what the temperature of the water is going to change to, I didn't see how that was going to be, that was going to find out what the energy was going to be in the food, I didn't know the connection kind of.

Later in the interview she returns to this issue:

S: You find out how much energy is in the food like I believe if you do that experiment and then you find out how much energy's in the food, I just don't understand how it actually all comes together and what you find out, like I know that (it) works, like if you do it you'll find out what the energy is, I just don't know why it works.

I: OK, this is really, really, really interesting because I mean you're grappling with a really important problem here, OK, let me get this straight, you understand everything that happens in the experiment, you know all the things that you do.

S: Yes. And like I believe that it works, like if Mr. Smythe told me that if you find out the energy by doing this, I'd say OK, like I'd say how you do the experiment that's how you find out what the energy is, but I don't see what the connection is between the energy and the temperature of the water.

I: Right.

S: Like I don't find out how you actually put them together and then why it works.

I: How you connect the temperature change in the water to the energy. That's the bit that you've still got to work out.

S: Yes, like why it happens.

I: But you believe it works because-

S: Mr Smythe told us.

Shona concludes the interview with a further statement of her dilemma:

S: I know how to do the experiment and everything, I just don't understand how it's all linked together and it tells you what the energy is.

Connecting with prior school mathematics experience

Hamish and Colin both participated in the same lesson on probability. The activity they did in the class involved a simulated horse race, with horses numbered from two to twelve (the possible outcomes of rolling two dice and taking the sum). Each race involved ten throws of the pair of dice and the students predicted which horse would be the winner. For Hamish, the learning was meaningful in that he made links with what he had done in grade 6, and showed that what was intuitive knowledge had become more sophisticated. He was able to articulate what he had understood the previous year and describe how his knowledge had developed. He was now able to explain why, when two dice are thrown, the chances of a seven are higher than for any other combination:

H: Well, I thought it would be easier to get more sevens because um, seven was in the middle and there would be more combinations of getting seven, like five and two, four and three, and six and one, but for numbers like twelve there'd only be one combination to get it, so I…

I: What did you understand before this year? If I'd asked you when you were in grade six?

H: I understood that seven or numbers in the middle of there like seven, six, eight, and five and nine are easier and even more likely to roll than the two dice than the twelve and the eleven, ten, one, two.
I: Could you do me the why? Could you explain that one to me?
H: Well, there's like these numbers like seven, eight and six and they're right in the middle and there's more combinations with the dice to get it and with ten there's only two combinations four and six, five and five, but with um, six, there's four and two, five and one, and three and three.

On the other hand, for Colin, who had participated in the same lesson, there appeared to be no development from grade 6 to year 7. He had a sense that it was the numbers "around the middle"that come up more often but had not yet grasped the notion of combinations, or *why* seven was the winner.
I: What about the bit where you backed the six and the seven and the eight ... and seven came out the winner?
C: Yeah, we did it last year in grade 6. Where it's usually around the middle that wins.
I: OK. What's educated about your guesses?
C: Well, that it's all around the middle.
I: Well, that's right, I mean you knew that, didn't you? Now what made you think that was true?
C: Because I did it last year.
I: And you did it once last year and it came out so you figure it's going to happen again?
C: Yeah, 'cause like the odds and all that. 'Cause there's more chance of getting things around the middle instead of up higher.

The sense of progression in understanding that is conveyed in Hamish's responses is absent from Colin's. The linkage which Hamish formed allows us to attribute a meaningful character to his learning, that does not apply in Colin's case. However, the restriction of the student's conceptual linkages to "within class" experiences poses serious questions with regard to the applicability of the student's learning to non-classroom contexts. While the linking of current content to previous studies in the same subject can be seen as an essential component of school learning, if this is the only form of linkage promoted or occurring, it is our feeling that the evolving understanding of concept or procedure is a fairly impoverished one.

Examples of meaningful learning
Using the criteria listed earlier, we were unable to find many instances of meaningful learning. In mathematics classes, where links with previous experience were made, none were with experiences outside the mathematics class. The example described above, of Hamish learning about probability, where he built on the knowledge he already had from the previous year is typical. Sarah, a year 8 mathematics student, provides another example in the context of learning about the difference between rate and ratio:
I: Do you feel like you learned anything new in this lesson?
S: Yeah ... Well, I know now what rate meant.
I: OK, so when did you decide you understood it?
S: Um, well first she related it to things we already sort of knew about, like about distance and time and all that kind of stuff we'd just done last year.

It was only in science classes that we found examples of students who made links with experiences outside the classroom. Sometimes these links were initiated by the teacher, and sometimes students responded by describing their own experiences. An illustrative example from a year 8 science class comes from Kevin, who, when dissecting a sheep's heart, drew on what he had learned from seeing his mother's ultrasound:

I: So when you talk about the four chambers, is that, are you picturing what you saw or are you picturing the diagram?
K: Well, I'm sort of picturing um, both, and um, well, Mum's going to have a baby soon.
I: All right.
K: And we, we saw an ultrasound.
I: Oh, OK.
K: And we saw the four chambers of the heart in the baby, um, all at once, and linking them in with the others in, so I sort of pictured that as well.

And further on in the interview, he was asked where he learned this:
I: So, in as much as you know something, whatever you got out of it afterwards, where did you learn that stuff from? Do you remember?
K: From the ultrasound probably, and well, well, we got videoed, think we took the video off back home so we could watch it on TV, and we, Mum sort of told a few things about it while we were watching...
I: What about [the fact that] the heart has four chambers? Where did you learn that? First time.
K: Ultrasound.
I: At the ultrasound and you really didn't know before then, that hadn't come up before then.
K: No.

Kevin's account illuminates two aspects of meaningful learning: the occurrence of purposeful and significant learning outside the classroom; and the significance of the prompted recall of prior out-of-class experiences as mechanisms to focus student attention on subject content.

In the following excerpt, a student in a mathematics class described the process of confirming her predictions:
I: So could you complete this sentence "in this lesson I learned that."
P: Um, I just really learned, well I kind of already knew but it just sort of put it into perspective how I realized that I already knew it but I didn't realize 'cause I sort of, you half, I half knew it but, but when you have the aspects when you fold it, will sort of change, but I already half-knew because it, but, well I already knew everything to go into it but I didn't know the combination, that they were in, do you know what I mean?
I: I think I, yeah, I think so.
P: The pieces, it was like a puzzle, that you sort of, I knew all the pieces I just had to put it together.
I: Yeah.
P: And that's where I didn't know, but I knew everything that went into it. So that was. 'Cause I knew how to do the aspect ratio and I had a feeling that when you fold it in half it would be equal because well, I had a feeling that this would happen, because when you fold it in half in, in the four it's just going to be a scale version of the bigger one, but smaller so it's going have the same aspect ratio, but it just sort of, I already had a feeling that I knew half of it, I just learned that it was really.

It appears that this student had experienced the empirical nature of mathematics, for it involved for her the observation of patterns, testing of conjectures, and estimation of results. Because of the links the student made with her own conjectures, we feel that this instance should also be regarded as an example of meaningful learning.

Conclusions

It appears that the Linkage Criterion (for Meaningful Learning) can be applied with success to data of the type generated in this study. It is noteworthy that of the 67 interviews analysed for this paper, less than 10 survived the stringent application of our criterion for meaningful learning. Within these examples, we have mentioned our concerns regarding the limitations of subject-specific linkages that make no reference to objects or events outside the classroom. Our data suggests that the role of out-of-class experiences as focussing mechanisms is a significant one. It is our intention to explore this particular outcome in a subsequent experimental study. Other issues to emerge included the recognition of intermediate states in the process of coming to know involving "transitional concepts" (Moschkovich, 1994). Student difficulties in articulating new knowledge raise the question of whether a claim to know can be made legitimately if the claimant is unable to express or demonstrate the knowledge claimed. Certainly, students in this study made claims to learning, but found the articulation of the new knowledge extremely difficult.

Is it the expectation of educators that students should acquire significant new knowledge in every lesson? It is our impression that teachers plan instruction with this goal in mind. Our data suggests that this goal is achieved sufficiently rarely as to call it into question. How frequently should we expect a student to engage in "Meaningful Learning" as defined by our Linkage Criterion? How important is it to distinguish the meaningful learning of a single fact or procedure, with whatever richness of association, from the more global form of meaningful conceptual learning, which the community has dignified with the term "understanding"? This distinction goes beyond Skemp's "instrumental" and "relational" categories for understanding (Skemp, 1976), since neither of these require reference to any objects outside the local system of mathematics (or science), which might have formed the basis for a lesson's content. It may be that the scale of the most meaningful forms of conceptual learning precludes their identification with any single lesson or activity, but rather are a consequence of a long-term synthetic process to which classroom events contribute incrementally. If this is the case, and if this form of learning is our ultimate goal, then classroom settings may not be either necessary or sufficient sites for our research.

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