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ABSTRACT

This paper presents a case study involving a small group of students enrolled in a tutorial program learning introductory college chemistry. The underlying theoretical framework of this investigation was a constructivist view of learning, but more specifically it was based on Ausubel's theory of meaningful learning. The findings of this investigation were: (1) students did undergo qualitative changes in their knowledge, but some students more so than others; (2) these changes were related to the students' learning approach, i.e., positively related to the adoption of a meaningful learning set (a predisposition to learn meaningfully); and to the nature (quality and quantity) of their prior knowledge; and (3) evidence suggested that at least one of the subjects changed from essentially a rote learner to a more meaningful learner. In addition, this study explored Ausubel's condition of adopting a meaningful learning set for meaningful learning to occur. (CW)

A CASE STUDY OF PRIOR KNOWLEDGE, LEARNING APPROACH AND CONCEPTUAL CHANGE IN AN INTRODUCTORY COLLEGE CHEMISTRY TUTORIAL PROGRAM

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INTRODUCTION

The study reported in this paper is about the phenomenon of learning from a constructivist view, with specific reference to the learning of introductory college chemistry. More specifically it is based on Ausubel's (Ausubel, 1968; Ausubel, et al, 1978) theory of meaningful learning. In light of this theory the primary assumption underlying the study is that meaningful learning of introductory college chemistry can profitably be viewed as a process of qualitative changes in the learner's prior knowledge (i.e., knowledge already held by the learner); and further, that this process depends on the way in which learners approach the learning task.

In order to investigate learning in this way, the study was conducted in the very interactive learning environment of a tutorial program. Because the study required detailed and extensive information about students, it was conducted as a case study involving a small group of students enrolled in an introductory college chemistry course and simultaneously in a tutorial program during the fall semester of 1986.

To operationalize the fundamental idea of meaningful learning as a process of qualitative (conceptual) changes, this study made extensive use of the model of learning as a process of conceptual change proposed by Posner, et al (1982) and further elaborated upon by Hewson (1981), where qualitative changes in a learner's conception can be described as changes in a conception's status of Intelligibility (I), Plausibility (P) and Fruitfulness (F). In addition, to complement Ausubel's distinction between rote and meaningful learning, the investigation also drew on Marton's (Marton and Saljo, 1976; Gibbs, 1981; Entwhistle and Ramsden, 1982), notion of surface and deep learning.

The specific research questions addressed by the study were the following:

1) Do tutorial students undergo qualitative conceptual changes that can be described in terms of changes in the conceptual status variables Intelligibility (I), Plausibility (P), and Fruitfulness (F), that results in more meaningful (more connected, more substantive, and more stable) knowledge?

2) Are these changes related to the students' learning approach?

3) Do some students change their learning approach over time?

In the next section, the theoretical framework underlying the study is discussed. Then the methods of data collection and analysis are outlined, and the results presented. Because of space limitations, these are a small sample of the results in the complete study (Braathen, 1987)

THEORETICAL FRAMEWORK AND REVIEW OF LITERATURE

The constructivist view of learning is that people gradually construct their knowledge during their lifetime in ways that make sense to them and that this knowledge undergoes both quantitative and qualitative changes over time. A person's knowledge at any time has important consequences for how behavior and actions are interpreted (Magoon, 1977). Moreover, because from a constructivist perspective, learning is an active process of construction and reconstruction of knowledge over a person's lifetime, learning is heavily dependent on that existing knowledge. The process of learning is therefore idiosyncratic, as is the resulting knowledge, represented by what West et al (1985) call "a private understanding" of a given subject matter.

Ausubel's theory of meaningful learning is certainly constructivist in nature. Ausubel's fundamental distinction is between rote and meaningful learning, where the latter is learning in which new knowledge is incorporated into existing cognitive structure in a substantive, rather than verbatim, manner and in a non-arbitrary fashion. The particular portion of existing knowledge in cognitive structure which is directly related to the new knowledge to be learned is called, in Ausubel's terms, a subsumer and most meaningful learning is thus a process of subsumption. During meaningful learning both new and existing knowledge undergoes a change in meaning, i.e., a qualitative (conceptual), as well as a quantitative, change.

According to Ausubel, two conditions must be satisfied for meaningful learning to occur (provided the material is meaningful): 1) the learner must possess relevant (related) prior knowledge, 2) the learner must adopt a meaningful learning set, i.e., a predisposition to learn meaningfully. If such conditions are not met then rote,

rather than meaningful, learning is the predictable outcome. These two conditions are fundamental parameters for the study reported in this paper. It is however important to recognize, as Ausubel does, that all learning will occur along some sort of a rote-meaningful continuum and thus an individual's knowledge will always be a mixture (with variable composition, to use a chemistry analog) of rote and meaningful.

That prior knowledge is positively related to learning outcome (at least as measured by achievement or success) have been well established within Ausubelian research (Ring, 1969; Ring and Novak, 1971; Novak, Ring, and Tamir, 1971). However, the exact role of prior knowledge on the quality (meaningfulness) of the learning of new material is far from established (Pines and Novak, 1985) and the effect on learning of adopting a meaningful learning set has only been directly assessed in one investigation (Talissayon, 1972). To cite Pines and Novak (1985): "...in effect, very few empirical test on Ausubel's theory have ever been done" (p. 213). One reason for this may be that Ausubelian based research has overwhelmingly focussed on the effects of advance organizers on learning, i.e., the provision, by means of instruction, of relevant prior superordinate knowledge which can serve to subsume the new material to be learned. Because the research is ambivalent about the efficacy of advance organizers (Barnes & Clawson, 1975; Mayer, 1979), this may have led to some disenchantment with Ausubelian ideas. This study, in contrast, does not focus on subsumers in instructional material, but on the learner's current state of knowledge, an idea we believe to be more central to Ausubel's theory than advance organizers. We regard what a learner knows and learns today as tomorrow's prior knowledge.

In this study we assume that meaningful learning can be viewed and described as qualitative changes in the learner's prior knowledge. In order to describe such changes this study made use of the model of learning as a process of conceptual change proposed by Posner, et al (1982) and further elaborated upon by Hewson (1981). Using this model qualitative changes in a learner's knowledge can be described as changes in the status variables Intelligibility (Can it be under-

stood?), Plausibility (Does it make sense?) and Fruitfulness (Can it be used? Does it have a purpose?) of conceptions held by the learner. For example, a conception not initially intelligible may become intelligible (Not I --> I). A conception which is intelligible but not plausible may become plausible (I --> P). A conception initially both intelligible and plausible but not fruitful may become fruitful as well (I, P --> F). Finally, a misconception held by the learner might have its status (in terms of I, P and F) lowered in favor of a more acceptable conception (a conceptual exchange).

The change I --> P is of particular importance to this study and will thus be clarified by an example. Periodic trends is a common subject in introductory college chemistry. During the investigation it was observed on many occasions that the conception that atomic radius decreases from left to right in a period is generally intelligible to most students. It is however seldom plausible unless further clarification beyond normal lectures is undertaken. This is because the conception is counterintuitive since atomic number (more electrons, protons and neutrons) increases as radius decreases.

The above changes all represent changes in the learner's prior knowledge and, very importantly, in the direction from less meaningful toward more meaningful. This is because intelligibility is the first step toward meaningful learning. True rote learning (probably rare) does not place any demand on intelligibility. Plausibility, on the other hand, constitutes one more step in the direction "more meaningful" because it must of necessity rely on a larger number of other conceptions.

The extent, however, that the changes described above can and will occur depends not only on the learner's prior knowledge but also on how the learner regards the learning task, i.e., in Ausubel's terms, whether or not the learner adopts a meaningful learning set. A slightly different view is provided by Marton (Marton and Saljo, 1976) who describes and distinguishes between surface and deep learning. In surface learning the learner does not go beyond the "sign" or the text, i.e., the learner is satisfied with definitions, formulas, algorithms, etc. In deep learning the learner goes beyond the mere "sign" or text, i.e., the learner seeks a more in-depth understanding

of what the material to be learned is really about. For Marton, then, an important variable is a person's learning approach, that is, the extent to which he or she seeks to go beyond the "sign" or text. While there is obviously a strong similarity between the ideas of a learning set and a learning approach, one possible difference is that a learner could learn signs and symbols meaningfully, in a connected fashion, i.e., he or she could exhibit a meaningful learning set while using a surface learning approach.

Another view, similar to these two, emerges from the model of learning as a process of conceptual change, as adapted by the researcher: the extent to which the learner questions the plausibility of a conception. This is demonstrated by a learner wondering, among other things, whether or not an idea makes sense to him or her. Because of the similarity, though not identity, between a learning set, a learning approach, and the questioning of plausibility, all three were assessed, as discussed below.

RESEARCH DESIGN

Methods

Since an in-depth understanding of the phenomenon of learning was the object of this investigation, the case study method was used because of its potential for generating very rich, qualitative data. The case of this investigation was a small group of students in one of the lecture sections of an introductory college chemistry course and simultaneously enrolled in the Chemistry Tutorial Program at the University of Wisconsin-Madison. The investigator was also these students' tutor (making it a "participant observation" study).

Initially the tutorial group under study consisted of five students. Concern about such small numbers, due to the possibility of subject "mortality," (possible attrition from the course and/or the tutorial program) led to some active recruiting after exam I, increasing the number of subjects/students to 10. However, as predicted, the degree of participation in the tutorial program and collaboration with the investigation was variable. Thus full data was obtained for only five subjects; three of the original five and two of the students who

enrolled after exam I. These five students represent, then, the case students. Because of space limitations, data on only three of the students is discussed below. For a complete discussion, the reader is referred to Braathen (1987).

To enhance internal validity of the study three methods of data gathering were employed.

Method 1. Tape recording of all tutorial sessions (approximately 70 over the semester). It was expected that during the tutorial sessions evidence would emerge of meaningful learning (in terms of changes of conceptual status), and indications of learning approach (in terms of students' demand, or lack of it, of higher level conceptual status i.e., plausibility and fruitfulness).

Method 2. Semistructured (flexible) interviews based on events from the tutorial sessions. This method had a two-fold purpose: 1) to follow up on interesting episodes that occurred during tutorial sessions, especially related to the acquisition of new knowledge and change in knowledge, as well as information on the stability of that knowledge, and 2) to elicit from students information about their learning approaches. This method was secondary in comparison to the other two methods.

Method 3. "Teachbacks" of selected topics before and after corresponding problem solving sessions. The term "teachback" was first introduced by Pask and Scott (1972) to refer to a method for assessing a student's learning approach. In this investigation it was additionally used to assess students' knowledge. The method, which is simple and very powerful, consists of the learner teaching back to the investigator a topic that he or she has been subjected to (for example in a lecture or discussion section) and is studying. The behavior of the investigator during the teachback is, however, critical, since, for example, not to interfere at all (say nothing) might produce little information from a reticent student. For this reason the investigator played the role of an interested and interactive student frequently interrupting with questions and demands for clarification.

The method was employed with four selected topics (based on the conceptual richness of the topic) as follows:

1. The gases and the gas laws (week 4)
2. Periodic trends and bonding (week 7)
3. Geometry of molecules (week 8)
4. Intermolecular forces (week 12)

The teachbacks were conducted as follows: The students would come in on Friday, prior to the scheduled problem solving tutorial (30 minute limit for each student). The researcher would explain to the student what he wanted him or her to do, and give him/her a written outline of the topic and aspects of that topic that the researcher was particularly interested in. For example, for the topic of periodic trends and bonding, these were:

1. Ionization energy, what it is, how it varies in the periodic table and why it varies the way it does.
2. Electronegativity, what it is, how it varies in the periodic table and why it varies the way it does.
3. The relationship between these two properties and ionic and covalent bonding, respectively.

The researcher would then ask the student to come back the next day, Saturday. He did not tell the student that the next day's interview would be a new teachback on the same topic. After the first series, however, they probably suspected that this would be the case. Due to the nature of the questions asked, however, we claim that this in no way harmed the validity of the method and the investigation.

In this study the method had a dual purpose. First, it was to assess the nature (quantity and quality) of a student's knowledge before (same day) and after (the next day) a tutorial problem solving session. More specifically, it was used to ascertain:

(1) what the students know about the topic at the time of the teachback (K variable), and
(2) to what extent the student's knowledge is meaningful or rote (M variable).

Second, the teachback method was used to infer the students' learning approach. More specifically it was used to ascertain:

(3) whether the student (the learner) approached the learning task adopting a meaningful learning set (S variable);

(4) whether the student (the learner) approached the learning task using a deep or surface approach (D variable); and

(5) whether the student (the learner) questions the "status" of a conception that he or she has been studying, with particular reference to the plausibility of that conception (P variable).

Data Reduction

The data of the investigation reported in this paper amounted to approximately 1500 single spaced pages of transcripts. Data reduction was, of course, mandatory. This was achieved in a number of ways. First, it was decided to limit analysis to the five students who had fully participated in the teachback procedure, since this was of fundamental importance for the investigation. The participation of each of these five students was then separated from the tutorial transcripts and changed into individual data bases that included the semistructured interview and teachback protocols. A preliminary analysis was carried out, in search of evidence of qualitative changes in knowledge and indications of characteristic learning approaches and changes in that variable.

Second, the data was restricted to that dealing with the chemistry topics being considered in and around the weeks of the teachbacks. While this left out many interesting issues and many instances of qualitative (conceptual) changes, it nevertheless represented about 2/3 of the semester and thus preserved an essential characteristic of a case study, namely an extended time interval.

Third, a more fine-tuned analysis was undertaken, which followed each student through each topic, focusing on instances of qualitative (conceptual) changes in knowledge, as well as looking for evidence of characteristic learning approaches. This in-depth analysis was organized around what we have termed Units of Analysis (UA), each unit representing a particular case student on one of the chemistry topics listed previously.

Data Analysis

The data collected and reduced as discussed above was analyzed for qualitative conceptual changes in the case students' knowledge. Such changes in knowledge were characterized and described in two ways: 1) In terms of changes in conceptual status of a conception over time, in terms of intelligibility, plausibility, and fruitfulness. 2) In terms of qualitative changes, which were assessed in a more indirect way, prior to and subsequent to a problem solving tutorial. This more indirect assessment was made by six independent judges who analyzed students' pre- and post-tutorial teachbacks, on the four different chemistry knowledge domains.

The learning approach of the case students was also assessed, since it was a fundamental concern of this investigation. This assessment was performed by the independent judges using the same teachbacks, as well as by the investigator whose assessment was based on both the teachbacks and the students' participation in tutorial sessions.

Although Marton's characterization of surface and deep learning (and thus of surface and deep knowledge) and Ausubel's characterization of rote and meaningful knowledge are relatively straightforward, judging instances of these as they occurred was no easy matter. Thus six independent judges were used for each teachback protocol to eliminate, as much as possible, subjective bias. The six judges were all experienced teachers of chemistry, with very strong backgrounds in this subject matter. Three held Ph.D.'s in Chemistry, one held an M.S. in Chemistry, one was a concluding Ph.D. candidate in Chemistry and one was about to finish a Ph.D. in Science Education related to chemistry.

The independent judging of the teachbacks turned out to be a much more elaborate enterprise than originally planned and will thus be discussed in more detail. After the investigation was concluded, the four sets of pre- and post-teachback protocols of the five case students were given to the six independent judges. Since each set of teachback protocols typically consisted of 30-40 single spaced pages, the independent judging procedure was a time consuming enterprise which took four weeks, since they were given one set of teachbacks (pre- and post-session on one topic) per week. The teachback protocols

were given to the judges in different random order and coded so as to keep the students anonymous. Further and very importantly, the judges were unaware of the fact that there were pre- and post-teachbacks. They believed that they were looking at the teachbacks of 10 students, rather than what actually was the case--pre- and post-teachbacks for five students.

In order to help the judges it was necessary to develop an instructional document where the terms to be judged were defined and exemplified as clearly as possible. The preparation of this document involved constant feedback and suggestions from the judges themselves. The efficiency of the document was tested by giving trial teachback protocols. After the document was finished, the judges were asked to judge the teachback protocols in terms of five statements, scored on a Likert scale: 1) strongly disagree, 2) disagree, 3) cannot say, 4) agree, and 5) strongly agree.

For the purpose of graphically representing these scores in an easily interpretable manner, they were afterwards changed to a scale from -2 (strongly disagree) to +2 (strongly agree) with 0 (zero) being the neutral score corresponding to "cannot say." The statements and ancillary commentary are presented in Table I.

RESULTS

In spite of all data reduction and limitations of the results presented, the results chapter of the original dissertation comprised 236 pages of double-spaced pages. This posed an intriguing challenge to the authors of this paper, namely how to present such extensive qualitative results in a shorter paper, as appropriate for the NARST meeting. The authors finally decided to do this in two parts, I and II, as follows:

I. A number of examples of qualitative (conceptual) changes in knowledge will be presented, based on excerpts from transcripts, for one case student (Eva) preceded by a short history.

II. Here, the purpose is to present an overview of three of the five case students (Eva, Ricardo, and Arthur) in order to look at the relationship between qualitative (conceptual) changes and learning

approach. Short histories of each student will be followed by a collapsed version of the graphic displays of the pre- and post-teachback judgments, i.e., all pre- and post-teachback graphs in one single figure (one for each case student) covering all four chemistry topics involved. In a sense each of these individual figures could be called the "Learning Print" for each student, since it very nicely and individually characterizes each one of the five case students. Finally, a discussion (interpretation) of the figures (the learning prints) will be presented and linked to the existence, or not, of frequent instances of qualitative (conceptual) changes in knowledge.

PART I: Instances of qualitative (conceptual) changes

Qualitative (conceptual) changes in knowledge were often observed during tutorial sessions with three of the five case students, and recorded as data in the corresponding transcripts of the audiotapes. It is, however, very important to note that tutorial sessions, with small numbers of students, are by nature very interactive and dynamic (we talk chemistry with the students rather than telling chemistry to them) and that the qualitative (conceptual) changes in knowledge did not occur in isolation but rather as a result of interactive discussion between the tutor and the students (as well as interactive discussions among the students themselves). Thus it was necessary, in the original dissertation, to present lengthy and numerous portions of transcripts, since such changes often occurred over an extended time interval and indeed, in some cases, over several tutorial sessions (maturation of conceptions) and thus over several days. In this paper, however, we will divide the instances of qualitative (conceptual) changes into episodes, narrating the circumstances and/or situations where they occurred and presenting only the parts of the transcripts where the qualitative (conceptual) changes are characterized (the "punch line" so to speak).

Eva - A Short History. Eva was a good, very interactive student, producing more instances of conceptual changes (over 100) than any of the other students. At the beginning of the semester, although very

competent in the mathematical aspects of the chemistry material, she gave the impression of learning in a superficial manner, i.e., never questioning the plausibility of what she was learning. This state of affairs is clearly characterized by transcripts from tutorial sessions, as well as by teachback protocols concerning Topic Number 1, the gases and gas laws. From this early part of the semester (the first month) no evidence of qualitative (conceptual) changes surfaced. However, her approach to her learning clearly, though gradually, changed as the semester went on, from typically rote to more meaningful. This is clearly evidenced from transcripts from tutorial sessions concerning Topic Number 2, periodic trends and bonding, and Topic Number 3, geometry of molecules, where numerous instances of qualitative (conceptual) changes in knowledge surfaced. Of particular importance are some more extensive changes that occurred with respect to Topic Number 3, geometry of molecules, where she apparently reached a learning peak both with respect to her knowledge and her learning approach. However, at the time of Week 12, it is equally clear from transcripts of tutorial sessions and teachback protocols concerning Topic Number 4, inter-molecular forces, that both her knowledge and her learning approach had qualitatively declined. Week 12, however, was a very stressful part of the semester, where the widespread impression was that the case students were tired of the chemistry course and generally apathetic. Especially with respect to Eva it is perhaps important to mention that she was sick at the time, especially so at the time of her post-teachback session which she attended only because of her commitment and responsibility.

Episode 1. The issue (in Topic 2, week 7) is relating periodic trends to chemical bonding (ionic or covalent). At the time of her pre-teachback on the issue she was on shaky ground (see "B" in Figure 1). At the end of this teachback however, she indicated that she is adopting a meaningful learning set when she says,

> I will come to the problem solving session because I really don't feel, you know...totally confident with this. It's like I understand how to apply some of it...but when it comes to explaining it, it's like...I don't know.

During the ensuing problem-solving tutorial this started to change and at a point she is rationalizing why NaCl, as an example, is an ionic compound.

E: Because there's a difference in electronegativities. One is high, the other is low. [I: Yeah.] Ahm, it's a difference in ionization energy. One is high and the other is low, and in radiuses, one is very small and one is large and therefore it's hard to take electrons from one radius but it's easy to put the same electron in the other, whereas, it's easy to take the electron from the other and harder to put it back in...
I: Yeah.
E: Does this make sense? (laughs)
I: Yeah, it makes total sense.

Her explanation was a little confused but in light of what (and how) she knew at the pre-teachback session (see graph) it seemed to represent an important qualitative (conceptual) change of the type: Not I --> I and then I --> P and thus a shift toward the more meaningful end of the rote-meaningful continuum. This is beautifully confirmed by her post-teachback protocol (see Figure 1).

Episode 2. The issue was molecular geometries (Topic 3, week 8). Eva arrived at a 1:1 tutorial (she had missed the regular small group session) with a great amount of prior knowledge related to the issue of molecular geometries. But at this point it seemed very rote (factual). During the session the investigator used molecular models very extensively to permit visualization of molecular shapes. The investigator started out explaining to Eva what VSEPR (Valence Shell Electron Pair Repulsion Model) stood for:

E: But that didn't make any sense to me, I did...you know...
I: But that electron pairs repel each other must make sense, right?
E: That's true, yeah. I should have seen that, but...

Although Eva had already figured out the geometries of some molecules, the underlying rationale for the VSEPR model had not yet been perceived or understood (i.e., it wasn't meaningful knowledge) and thus the episode represents a change of the type I --> P.

Episode 3. We are now (in the same session as Episode 3) talking about the $BeCl_2$ molecule:

E: Well, the...it will be (writes on the board)...that couldn't possibly be right (questioning plausibility) (small pause).
I: All right. Why not? What's the...
E: Well, then they are at the 180 degrees and they are really far apart.

I: Yes, so this molecule is what?
E: Linear!! (with strong emphasis)
I: Linear, yes.
E: Whaattt (laughs). Nooooo!
I: Yes. Linear. [E: (laughs)] Okay. Here's how the molecule looks (investigator show her a model).

The type of change here was at least Not P --> P, but perhaps it hadn't even been intelligible (meaningful) to her, and then it would have been a shift from Not I --> I, as well.

Episode 4. At the same session as Episodes 2 & 3, an example of a higher order conceptual change, where even the fruitfulness of a conception is engaged, occurred next:

E: What it looks like to me, and I'm not sure if this is right, you can figure out any of them.
I: Yeah.
E: Just by using...I mean most of them (meaning without the use of rules) unless they give you an octahedral (prior knowledge) or something totally ridiculous.

This represented then a change of the type I, P --> F. That these episodes represent qualitative (conceptual) changes is confirmed by the following dialogue:

I: This model, I think that it didn't make any sense to you before we started talking about it.
E: It didn't. It didn't at all (laughs).

Episode 5. Over several tutorial sessions it had become clear that Eva is having a lot of trouble (lack of intelligibility and thus, of course, of plausibility) with the issue, related to molecular geometries, of polarity of molecules. During some time she was tenaciously hanging on to the conception of symmetry of molecules to decide if a molecule was or was not polar (however, as became increasingly clear, without really understanding what polarity is). This led her frequently to wrong decisions since, as she confessed, the issue of symmetry was not at all clear to her either. However it became clear that the problem went well beyond that. The problem was that she just did not understand what polarity meant. What a dipole moment is, and why a molecule would or would not be polar, are issues which are based on these conceptions. At tutorial sessions the investigator would repeatedly use the arguments of differences in electronegativities

of the atoms in a molecule, the net polarization of bonds in terms of molecular geometries and the physics analogy of resultant forces.

I: (writes on the board) so you see...
E: But...you have two (the CO_2 molecule) ahhh! Can't say, you have two around it and like the positive in the middle so by the time you end up..it's...

This is the first indication that a qualitative (conceptual) change of the type Not I --> I and then I --> P is on its way. A little later this is confirmed when she concludes that the NH_3 molecule is polar, using the arguments of differences in electronegativities and net polarization of bonds, and then she undergoes a higher order conceptual change and far transfer, indicating also a deep learning approach. She takes the NH_3 stick and ball model and:

E: But if it looks like this (Eva takes the trigonal pyramidal "molecule" and presses it against the table so it becomes trigonal planar).
I: Then it would be what?
E: Then it wouldn't be...polar!
I: Non...
E: It would be non-polar.

That she finally understood (I and P) what polarity is and why molecules would or would not be polar was continuously confirmed in later tutorial sessions, when the issue surfaced again.

Episode 6. We are discussing geometries of molecules. Eva knows the names of the shapes but apparently at least some are devoid of meaning (Not I, Not P?). We are looking at the model of the BCl_3 molecule.

I: It looks like a triangle, doesn't it?
E: Yeah.
I: Okay, but its on the plane because...
E: Yeah.
I: And because it's on the plane...
E: Planar!! (with emphasis)
I: Planar.
E: Oh! Ohhhhhh! That's where it gets the name from!

This represents a change of the type Not I --> I, and then I --> P. It also represents, of course, a shift along the rote/meaningful continuum.

Episode 7. In the last episode presented here (we have a collection of over 100 examples of qualitative changes, some trivial some

more extensive, involving Eva over the semester), we cannot probably claim that a qualitative (conceptual) change of the type I --> P did in fact occur. We do include it, however, since it exemplifies a very nice instance of a conceptual conflict where plausibility could not be attained in view of limitations of the learner's prior knowledge. It had to do with the trend that atomic radii decreases, from left to right, in a period in the periodic table. It is interesting to note that Eva knew that was indeed the trend but when confronted with explaining it the following dialogue took place:

I: Why does it get smaller and smaller over here?
E: Fewer electrons?
I: As we go across the period?
E: Nooo, but the (sighs distressed)
I: The number of electrons get bigger, right?
E: Yeah.
I: But how does the atoms get smaller, that's tough...
E: Yeah.
I: ..to understand (pause). Why would you say it is Eva?
E: Ahm, oh, let's say the atoms get smaller...(small pause)

Although this counter-intuitive idea bothers her, she apparently resigned herself to accepting it (rote learning). The investigator wouldn't let her, however:

I: Yeah, but why should that be?
E: Why? Oh! Geez..(small pause). More electrons, but that doesn't...
I: It doesn't make sense, right?
E: No (sighs).
I: I agree with you. It doesn't make sense.

The investigator explained to the group how this "strange" phenomenon could be rationalized. Eva seemed to be understanding what the investigator was saying, but in a follow-up interview, early next week, it was clear that this issue was still not clear, i.e., it was not totally plausible to her.

PART II: Short histories, graphic displays of the teachback judgements and interpretation of the graphs

A key to the graphic displays is presented in Table II. The graphs should be self-explanatory even though the judging is by nature subjective (which is why six judges were used) and the authors do not intend to tell the readers "what to see" or what to make of the graphs.

Eva - The teachback judgment. Figure 1 gives a picture of Eva's knowledge (K and M), perceived learning approach (S, D, and P) and changes in these variables, as perceived by the six independent judges based on the pre- and post-teachback protocols.

Discussion (interpretation) of the teachback graphs.

a) The gases and the gas laws. Both pre- and post-teachback graphs show reasonable inter-judge agreement with respect to Eva's knowledge and perceived learning approach. The salient aspects seems to be that the quantity of her knowledge increased between pre- and post-teachbacks. However, little indication exists that it was meaningful, that it had become more meaningful between pre- and post-teachbacks, or that she was perceived as adopting a meaningful learning set or a deep approach. Of fundamental importance for this investigation is the fact that during this unit of analysis no evidence of qualitative (conceptual) changes was perceived by the investigator.

b) Periodic trends and bonding. Here the important aspect seems to be that the inter-judge agreement on the pre-teachback is very poor. This indicates that it must have been difficult for the judges to make clear distinctions. However, of fundamental importance for this investigation is that on her post-teachback inter-judge agreement is almost perfect and overwhelmingly positive on all variables. There can be no doubt that important changes occurred between pre- and post-teachbacks (between Friday and Saturday!). As was seen in Part I, numerous examples of qualitative (conceptual) changes in knowledge occurred in this unit of analysis.

c) Molecular geometries. There is not much to discuss here. Essentially she is knowledgeable, her knowledge is perceived to be meaningful both on pre- and post-teachbacks, she is perceived to adopt a meaningful learning set and even a deep approach and to question plausibility of conceptions, both on the pre- and post-teachbacks Her post-teachback might be considered less good than her pre-teachback. A plausible explanation, in view of existing data, is that her post-teachback was longer, that she engaged issues not specifically called for, and thus she extended or overreached herself. During this unit

of analysis very important qualitative (conceptual) changes took place, as was seen above.

d) Inter molecular forces. Again there is not much to discuss except that both her pre- and post-teachbacks were clearly disastrous. No indication of any qualitative (conceptual) changes in knowledge took place in this unit of analysis.

Ricardo - A short history. Ricardo started the semester with what appeared to be a solid prior knowledge background (conceivably because he was retaking it with the purpose of getting a better grade) and indeed his "best" performance was at the early part of the semester (up to Exam I). After this, however, his performance steadily deteriorated, and he was perceived as being a rote/surface learner throughout the whole semester. As a consequence some very disturbing post-tutorial teachback judgments surfaced. Also, few, if any, examples of qualitative (conceptual) changes in knowledge were perceived by the investigator.

Ricardo's case was very interesting, but is a very difficult one to interpret. There is no doubt that Ricardo studied a great deal, and thus his continuing decline in performance, as measured by quizzes and exams, must have been perplexing and very distressing to him. Ricardo frequently gave the impression of being overwhelmed by the chemistry knowledge of the course and thus very often his knowledge appeared to be confused and disorganized. Also, with the possible exception of the first set of pre- and post- teachbacks (Topic 1, the gases and the gas laws) his post tutorial teachbacks were invariably seen as worse than the corresponding pre-tutorial teachbacks (and in two cases dramatically so) by the independent judges. It is important (and fair) to mention that English was Ricardo's second language, a fact that might conceivably have affected negatively the judges' opinion on his teachbacks. As a matter of fact, several times a judge would ask in the margins of his teachback transcripts if "this student" had language problems. This was undoubtedly the case, although the investigator would claim that it was not overly so. In all Ricardo's units of analysis there were few, if any, instances of qualitative (conceptual) changes in his knowledge.

The teachback judgments. Figure 2 gives a picture of Ricardo's knowledge (K and M), perceived learning approach (S, D, and P) and changes in these variables, as perceived by the six independent judges based on the pre- and post-teachback protocols.

Discussion (interpretation) of the teachback graphs.

a) The gases and gas laws. The first impression is that inter-judge agreement is not good, either for pre- and post-teachback. This illustrates well what was observed by the investigator, over the whole semester: there was a confusing nature to Ricardo's knowledge and difficulty in making decisions about his learning approach. Second, it is possible his knowledge was more extensive between pre-and post-teachbacks (recall there was a problem solving tutorial in between. Recall also that neutral scores do not appear on the graphs).

b) Periodic trends and bonding. Inter-judge agreement on the pre-teachback is very bad. However, it is good on the post-teachback but very negative on all variables, illustrating the peculiar fact that Ricardo's knowledge and perceived learning approach was generally perceived to be worse on his post-teachbacks.

c) Geometry of molecules. Inter-judge agreement on the pre-teachback is again poor but is better than the post-teachback. However, we see again an apparent deterioration of knowledge and perceived learning approach.

d) Inter molecular forces. This is perhaps the strangest case of all, involving Ricardo's teachbacks. The pre-teachback is his best ever, but his post-teachback indicates again a deterioration of knowledge (both quantity K, and quality, M) and perceived learning approach.

Arthur - A short history. Arthur was obviously the best of the case students, always very knowledgeable and undoubtedly a meaningful and deep learner. It is true that he underwent few qualitative (conceptual) changes in his knowledge describable in terms of changes in the status variables I, P, and F. In his case, however, this can easily be explained by assuming that there was not very much to be changed. On the other hand, a more in-depth analysis of his pre- and post-teachback protocols would certainly (see graphs) reveal that nevertheless

his knowledge (and even perceived learning approach) generally improved (thus a qualitative change) between pre- and post-teachbacks.

The teachback judgments. Figure 3 gives a picture of Arthur s knowledge, perceived learning approach, and changes in these variables.

Discussion (interpretation) of the teachback graphs. Note that the graphs are generally and overwhelmingly positive, although with some disagreement among judges with respect to Topic 3 (geometry of molecules). Note also that the post-teachbacks are invariably better than the pre-teachbacks.

CONCLUSION

The purpose of the study reported in this paper was to investigate the learning of introductory college chemistry. This was done by concentrating on some prior knowledge held by the learner/subject at a given point in time, and describing the changes in that knowledge, both quantitative and qualitative, but focusing primarily on the latter, in relation to the nature of the learner's prior knowledge and his or her learning approach.

Such changes in knowledge were characterized and described in two ways: 1) In terms of changes in conceptual status of a conception over time, in terms of intelligibility, plausibility, and fruitfulness. 2) In terms of qualitative changes, which were assessed in a more indirect way, prior to and subsequent to a problem solving tutorial. This more indirect assessment were made by six independent judges who analyzed students' pre- and post-tutorial teachbacks, on four different chemistry knowledge domains. Since learning approach was fundamental concern of this investigation, it was also assessed by the independent judges based on the same teachback as well as on students' participation in tutorial sessions.

With respect to the research questions posed in the study, numerous qualitative (conceptual) changes were documented. A significant feature was that these changes were demonstrably more numerous and extensive for three of the case students (Eva, Arthur, and one other) than for the remaining two (Ricardo and one other). In this paper, however, data was only presented for Eva. A strongly affirmative

answer than therefore be given to the first research question; tutorial students underwent qualitative changes which resulted in more meaningful knowledge.

Second, there was clear evidence that the qualitative changes described above were related to the student's learning approach and to the quantity and quality of prior knowledge. For example, such changes were most numerous when the student had clearly adopted a meaningful learning set and had a reasonable amount of knowledge. Such was the case for Eva in Topics b) and c). Also when a student had adopted a meaningful learning set and had prior knowledge which appeared to be already meaningful, the changes were typically fewer in number and more extensive in nature, as was the case with Arthur. The available evidence therefore indicates that qualitative changes in a student's prior knowledge are related to his or her learning approach.

Answers to the second research question depended on the independent judging of the teachbacks. As was seen in Figures 1-3 there was on most teachbacks considerable agreement between the judges. On occasion, however, there was total disagreement. Possible explanations include inconsistent judging, lack of clarity about the meaning of the categories being judged, and the complexity of the judging task. Because of the large amount of overall agreement between judges who were qualified and experienced, we would reject the first explanation. There may well be some validity in the second explanation. In our view, however, the third explanation is most plausible. The task required the consideration of a large number of different statements in a teachback which was typically thirty pages in length. Particularly when one is trying to balance the contrasting, inconsistent statements of a student whose understanding of a topic may be insecure, it is not surprising to find that the judges' interpretations were wide ranging.

Finally, the available evidence suggests that four out of five case students used essentially the same learning approach throughout the semester. The only one who gave indications of changes in learning approach was Eva. The data suggests that these changes could be topic dependent. Clearly more research is needed before a clearer answer

can be given to whether, and if so, how learning approaches change over time.

This investigation gives strong support to Ausubel's theory of meaningful learning and the importance of prior knowledge and the adoption of a meaningful learning set. Very important, from a theoretical perspective, is the nature (quantity and quality) of prior knowledge. In other words, the prior knowledge held by a learner can be more or less meaningful to start with. Evidence from this investigation suggests that if prior knowledge is situated very much toward the rote end of the rote/meaningful continuum, qualitative (conceptual) changes (meaningful learning) are unlikely to occur. Comparisons of several pre- and post-teachback graphs seem to support this. On the other hand, results from this investigation support the idea that in many cases when prior knowledge is further along the rote/meaningful continuum, but still very rote/surface, this knowledge is ripe, so to speak, for a process of integration, and that in these cases qualitative (conceptual) changes are more likely to occur.

Furthermore, it must be recognized that Ausubel's fundamental notion of the need for the adoption of a meaningful learning set for meaningful learning to occur, has been very poorly explored in Ausubelian research. This investigation has thus contributed very significantly in exploring this issue by directly assessing the adoption of a meaningful learning set. This was done by analyzing what the learner is saying (is she or he relating new knowledge to existing knowledge?) as well as assessing it by telling independent judges (all educators) what it means to adopt a meaningful learning set and then asking them to ascertain from transcripts of teachbacks, if the learner seemed to have adopted such a learning set.

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TABLE I

Table I Statements and criteria for independent judging of teachbacks.

	STATEMENT	COMMENTARY
1.	This student appears knowledgeable with respect to this topic	In judging whether this statement applies, consider whether the student: --knows the topic (without dwelling too much on the quality of that knowledge). --Possesses a fair amount of information about the topic
2.	I would say that this student's knowledge is essentially meaningful	In judging, consider whether the student's knowledge is: --More than just a collection of bits and pieces of factual information. --Essentially an integrated "chunk" of knowledge. --More toward the meaningful end of the rote-meaningful continuum.
3.	This student appears to have adopted a meaningful learning set with respect to this topic.	In judging, consider whether the student: --Conveys an impression of intent or predisposition to learn meaningfully. --Has the desire to connect or integrate knowledge. --Wants to do more than memorize bits and pieces of factual information.
4.	This student appears to have used a deep approach while learning this subject.	In judging, consider whether the student attempts: --To go beyond the sign (symbols, definitions, etc.) or text. --To explain or interpret the information rather than just tell or recite.
5.	Plausibility of a conception is an issue with this learner/student.	In judging, consider whether the student: --Indicates discomfort and self questioning of what he/she is saying. --Questions the plausibility of conceptions.

TABLE II
KEY TO THE TEACHBACK GRAPHS

The graphs depict the teachback judgments of six independent judges. The bar shadings differ for each judge.

The graph on the left side (A) corresponds to the pre-teachback judgement. The graph on the right side (B) corresponds to the post-teachback judgement.

The content topics in each figure are from top to bottom:

a) The gases and the gas laws
b) Periodic trends and bonding
c) Geometry of molecules
d) Intermolecular forces

The scores in figures 1-3 vary as follows:

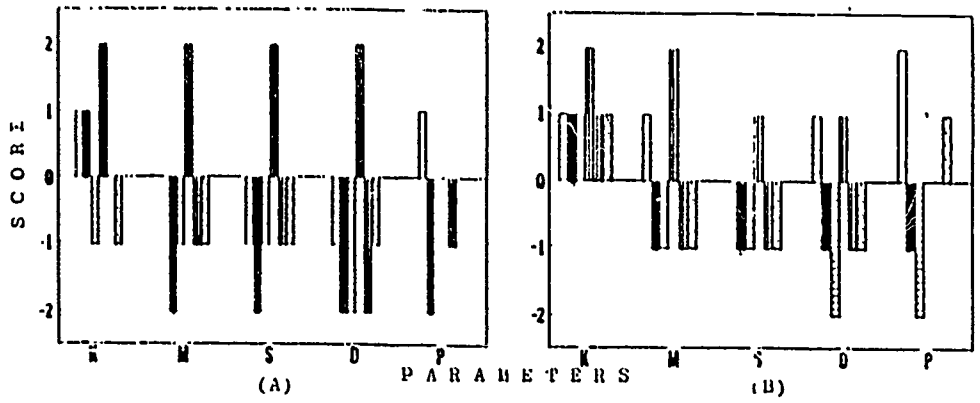
+2 Strongly agree
+1 Agree
0 Cannot say
-1 Disagree
-2 Strongly disagree

In the case of a score of zero (0), the corresponding judge does not appear on the graph.

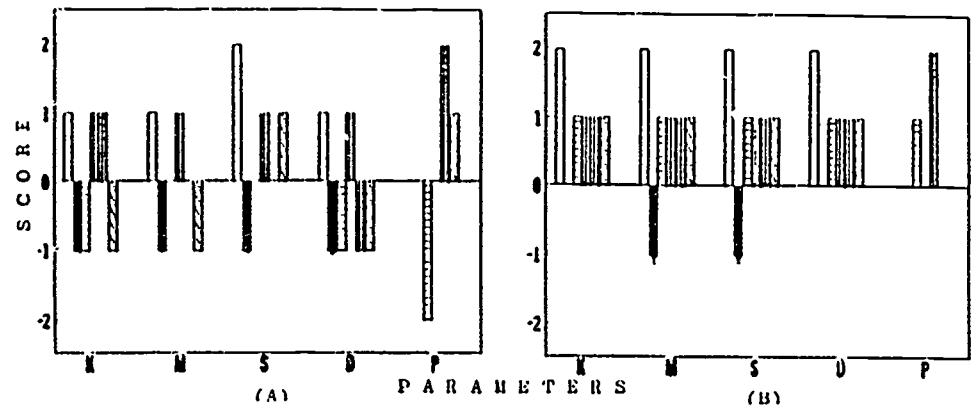
The statement variables, or parameters, are represented by:

K - Knowledge
M - Meaningfulness of that knowledge
S - Existence of a meaningful learning set
D - Deep approach to learning
P - Questioning of the Plausibility of conceptions

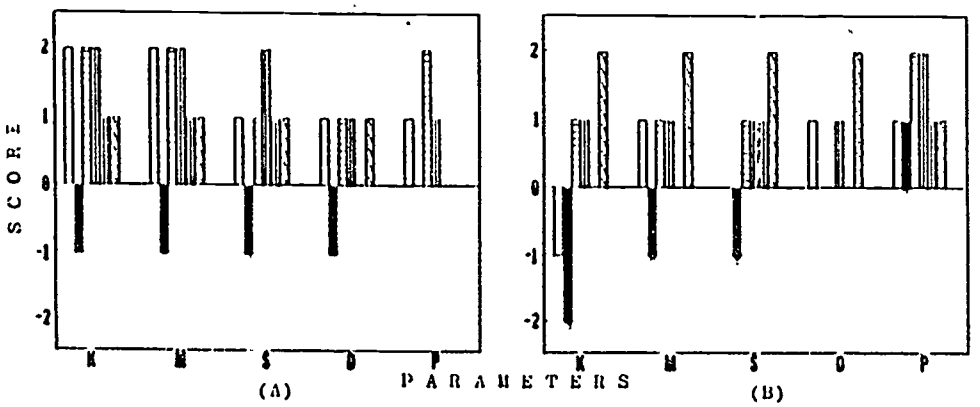
(a)



(b)



(c)



(d)

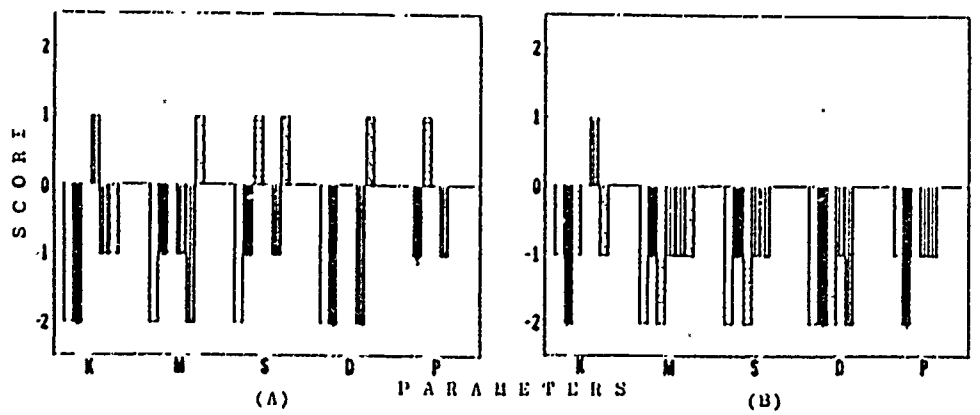


FIGURE 1: SUMMARY OF TEACHBACK JUDGMENTS FOR EVA.
SEE TABLE II FOR KEY TO GRAPHS.

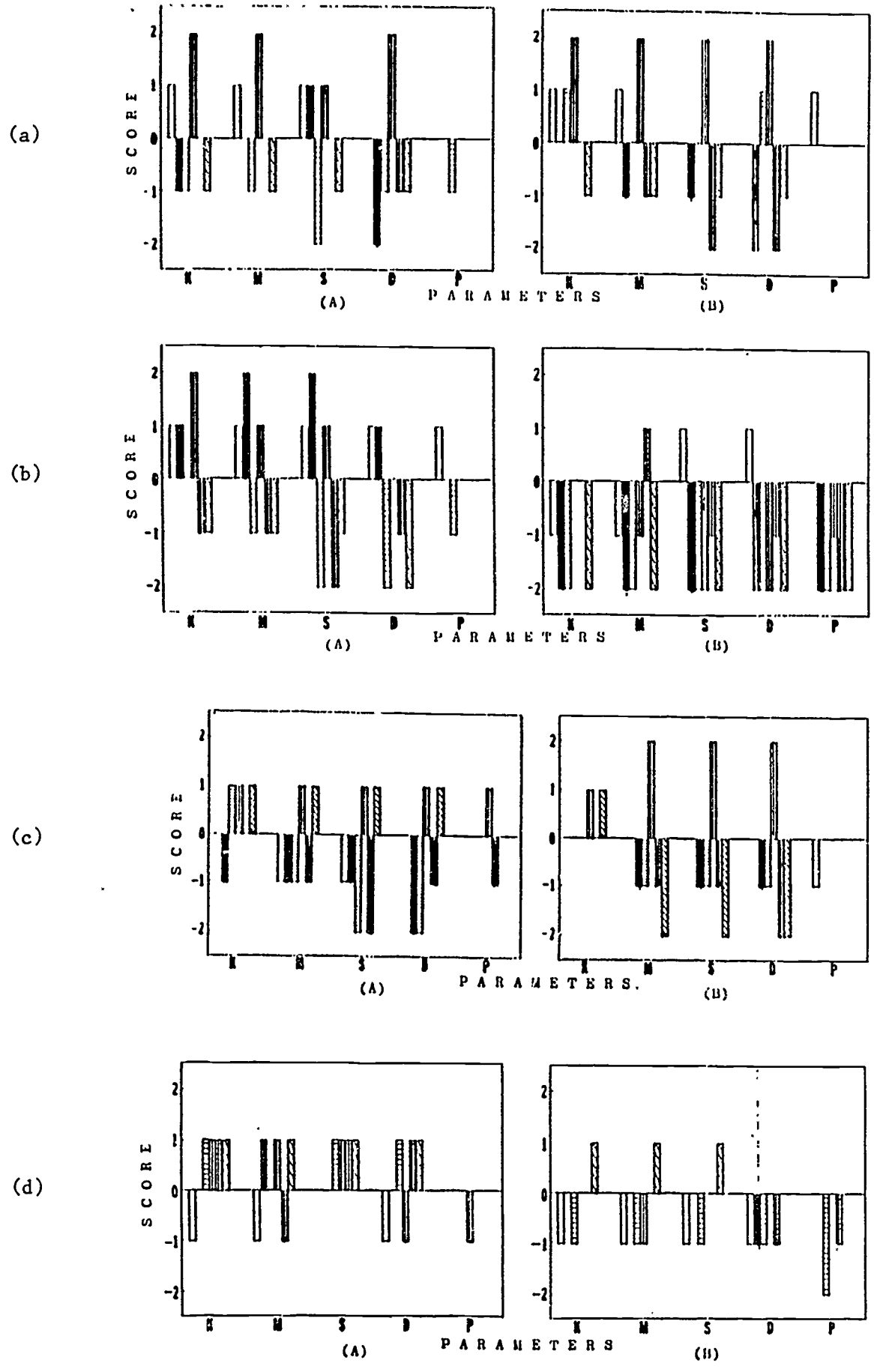


FIGURE 2: SUMMARY OF TEACHBACK JUDGEMENTS FOR RICARDO. SEE TABLE II FOR KEY TO GRAPHS.

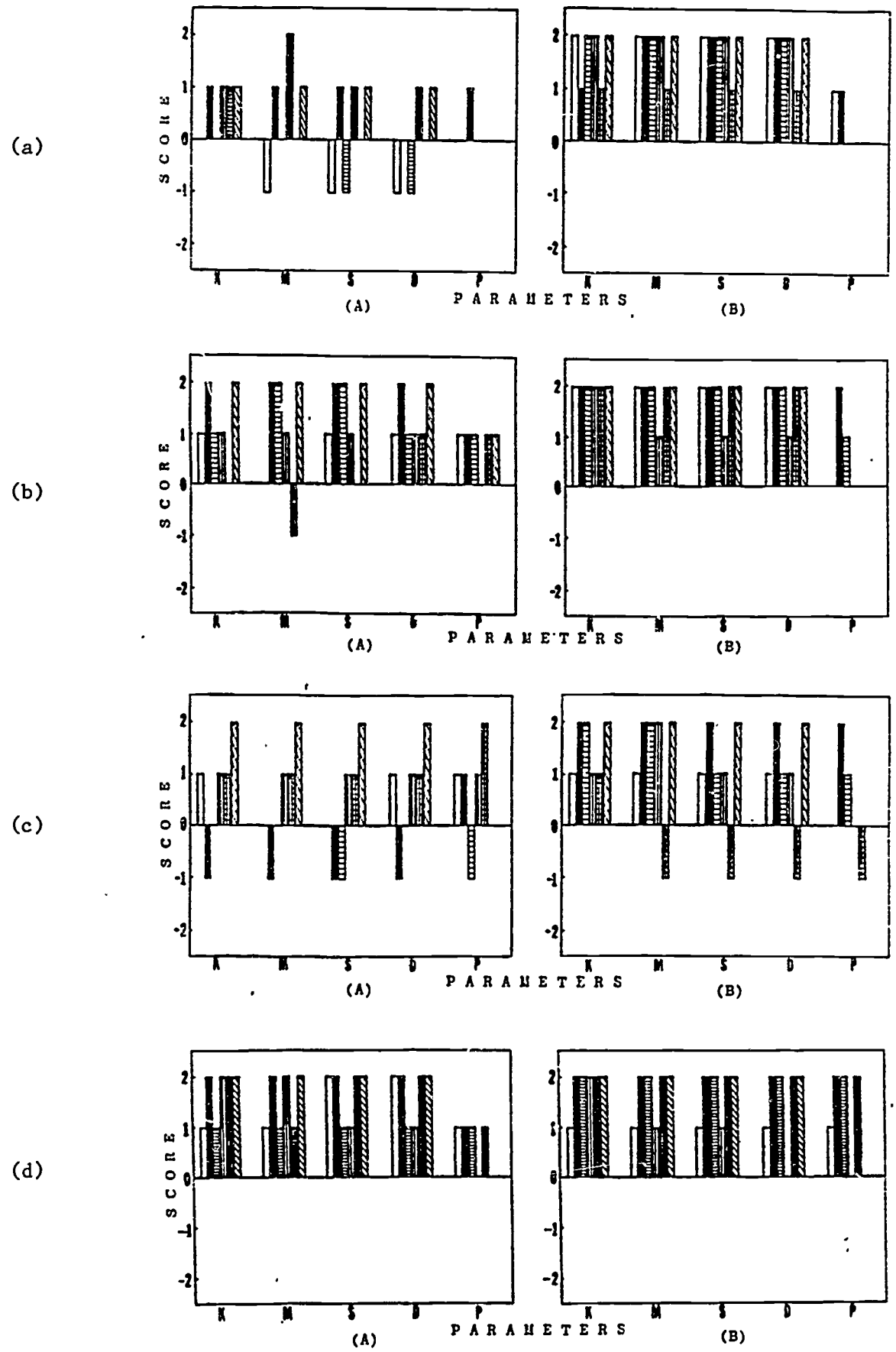


FIGURE 3: SUMMARY OF TEACHBACK JUDGEMENTS FOR ARTHUR. SEE TABLE II FOR KEY TO GRAPHS.