

THE PRESENTATION SEQUENCE OF GAS PROPERTIES BY PHYSICS TEXTBOOKS AND SCIENCE TEACHERS' REPORTS

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Abstract

In this paper, the presentation of the sequence of gas laws is examined to identify cognitive gaps which can hinder student understanding of the concepts involved. Analysis of 14 physics textbooks used in Australian secondary schools and questionnaires from 104 science teachers provided the data for the study. Analysis of the teachers' reports reveals features of the gas law sequence which are inconsistent with the textbook analysis; namely, a low usage of the historical sequence for the gas laws, the use of a sequence which is not necessarily logical, and the use of a simple to complex sequence with no cognitive gaps. The manner in which textbooks can constrain teachers' presentation of concepts and exercises is discussed.

INTRODUCTION

Appropriate sequencing of information has almost intuitively been regarded as an important component of instruction and learning. Bruner (1966) included effective sequencing as one of the four major features of his theory of instruction and Ausubel (1968) linked content structure in teaching to the learner's structure of knowledge by suggesting that a content structure which sequences from more inclusive to less inclusive concepts will facilitate learning. Gagné (1965) postulated, however, that learning occurs best when one moves from the mastery of small conceptual units to the more general and more inclusive units. However, when discussing the learning of scientific categories, White (1988, p.36) concluded that it does not matter whether instruction begins with the more inclusive or less inclusive concepts if a 'pattern of association' exists between the elements of the instructional package. Novak (1977, p.126) draws upon Ausubel's concepts of progressive differentiation (more inclusive to less inclusive) and integrative reconciliation (less inclusive to more inclusive) to indicate that movement both ways in a knowledge hierarchy is important if new information is to be integrated into a knowledge structure.

An examination of the process of integrating small elements into larger elements or differentiating large elements into small elements can lead to the detection of cognitive gaps:

Cognitive gaps occur when the transition from one element to another in a presentation sequence is not obvious because of the omission of a crucial incremental concept although the transition is often regarded as obvious. Thus patterns of association between elements in a knowledge structure lose their integrating power in the presence of cognitive gaps. One of the purposes of the research reported here was to examine gas law sequences as presented by physics textbooks and by science teachers for the presence of cognitive gaps and to define the nature of these gaps if they exist. The historical sequence is considered in the analysis reported here because a preliminary historical analysis of the development of the gas laws (de Berg, 1988) showed that $V \propto n$ or $P \propto n$ was omitted from the historical sequence thus introducing a cognitive gap between $PV/T = \text{constant}$ and $PV = nRT$. The extent to which such a sequence was used by textbooks or teachers was therefore considered worthy of investigation.

Novak (1977, p.94) considers the ordering of concepts in a knowledge base for instruction in terms of logical order and psychological order. Psychological order occurs when instruction deals with concepts at all levels of the conceptual hierarchy in a cyclic fashion as referred to previously. Logical organization places all information relevant to a concept in a single location. In the case of the gas laws, a logical organization could commence with $V \propto 1/P$ and consider $PV = \text{constant}$ at

the same time, whereas a psychological organization may consider $PV = \text{constant}$ after $PV = nRT$ has been introduced so that $V \propto 1/P$ and $PV = \text{constant}$ could occur at different locations in the hierarchy. The extent of logical organization of gas law sequences in physics textbooks and according to science teachers' reports was therefore another consideration of the research reported here.

DATA COLLECTION AND ANALYSIS

A teacher report instrument was constructed and drafts were examined by three science teachers of physics for suitability of content and presentation, by three science educators for suitability of the pedagogic content and questionnaire construction, and by a university physics lecturer for science content validity. On the basis of comments received from these three groups of people the final draft contained two sections. Section 1 examined teachers' dependence on textbooks for content, exercises and sequencing, teachers' use of the history of science and qualitative-quantitative aspects, the derivation format of the combined gas law and the use of Avogadro's Hypothesis, Boyle's and Gay-Lussac's Law; Section 2 contained three questions concerning gas law sequence, laboratory orientation and problem solving. In Section 1 teachers were to record their perception of the teaching situation described on a continuous Likert scale from 0 to 8 where '0' represents 'never', '2' represents 'sometimes', '4' represents '50% of the time yes, 50% of the time no', '6' represents 'mostly', and '8' represents 'always'. In Section 2 teachers were required to record the sequence of gas law presentation, the method of presenting these gas laws, and the solution type for a gas problem involving percentage composition by

mass. In this paper we confine ourselves to those aspects of the questionnaire relating to textbook dependence and gas law sequence.

DATA SOURCE

The 14 physics textbooks used in the analysis are presented in the Appendix. The questionnaire was completed by 104 teachers of Years 11 and 12 physics, chemistry or physical science from 49 high schools in Western Australia and the Northern Territory. The teachers were asked to complete the questionnaire from the point of view of how they teach the topic given the normal constraints they experience from day to day.

DATA ANALYSIS

The data from the seven items dealing with teachers' dependence on textbooks for content, exercises and sequencing in Section 1 of the questionnaire were analysed to provide descriptive statistics comprising the mean and standard deviation. Data from Section 2 of the questionnaire dealing with gas law sequences were coded before entry to the data base and analysed as percentages in selected categories. The first question of Section 2

requested teachers to indicate the order they would probably present the eight mathematical expressions of the gas laws. The jumbled order of expressions was:

- (a) $PV = \text{constant}$
- (b) $V \propto n$ or $P \propto n$
- (c) $V \propto T$ or $P \propto T$
- (d) $PV/nT = \text{constant}$
- (e) $V \propto T/P$ or $P \propto T/V$
- (f) $PV = nRT$ or $PV = nkT$
- (g) $V \propto 1/P$ or $P \propto 1/V$
- (h) $PV/T = \text{constant}$

The teachers were asked to select only the expressions they actually use.

Gas law sequences are classified as A, B or C. For sequence classification A, the sequences are coded in terms of their relationship with the historical sequence (de Berg, 1988). If the sequence corresponds to that which represents the sequential historical development of the topic, it is coded A-0. Non-historical sequences are classified in three ways. If the non-historical sequence begins with either a volume or pressure-temperature relationship and elsewhere resembles the historical sequence, it is coded A-1; if it contains the volume or pressure-mole relationship it is coded A-2; other sequences are coded A-3. Examples of these different sequences for classification A are given in Figure 1.

A-0	A-1	A-2	A-3
$V \propto 1/P$ $PV = c$ $V \propto T$ $PV/T = c$ $PV = nRT$	$V \propto T$ $PV = c$ $PV/T = c$ $PV = nRT$	$PV = c$ $V \propto T$ $PV/T = c$ $V \propto n$ $PV/nT = c$ $PV = nRT$	$P \propto D$ $\Delta V \propto \Delta T$ $\Delta P \propto VT$ $P = kDT$

Figure 1: Examples of sequences under classification A where

- A-0 → historical;
- A-1 → historical except sequence starts with $V \propto T$;
- A-2 → sequence includes $V \propto n$;
- A-3 → other.

RESEARCH

Text	Sequence -->			A	B	C			
Barrell (1962)	$V \propto \frac{1}{p}$	$PV = c$	$V \propto T$	$P \propto T$	$\frac{PV}{T} = c$	$PV = nRT$	0	1	0
Booth & Nichol (1962)	$V \propto T$	$PV = c$	$\frac{PV}{T} = c$	$PV = nRT$			1	1	0
Beiser (1962)	$PV = c$	$\frac{V}{T} = c$	$\frac{PV}{T} = c$				0	0	0
Smith & Smith (1964)	$\frac{V_1}{V_2} = \frac{T_1}{T_2}$	$\frac{P_2}{P_1} = \frac{T_2}{T_1}$	$PV = c$	$\frac{PV}{T} = c$			1	0	0
Haber-Schaim (1971)	$V \propto T$	$\frac{1}{V} \propto P$	$PV = c$	$\frac{PV}{T} = c$	$PV = nRT$		1	1	0
Project Physics (1973)	$P \propto D$	$\Delta V \propto \Delta T$ verbal	$\Delta P \propto \Delta T$ verbal	$P = kDT$			3	0	0
Murphy (1982)	$PV = c$	$\frac{V_1}{V_2} = \frac{T_1}{T_2}$	$\frac{PV}{T} = c$				0	0	0
Hunt (1982)	$P \propto T$	$V \propto T$	$V \propto \frac{1}{P}$	$PV = c$	$\frac{PV}{T} = c$	$PV = nRT$	1	1	0
Pople (1982)	$\frac{P}{T} = c$	$\frac{V}{T} = c$	$PV = c$	$\frac{PV}{T} = c$			1	0	0
Keighley et al. (1982)	$P \propto \frac{1}{V}$	$PV = c$	$P \propto T$	$\frac{PV}{T} = c$			0	0	0
Anderson (1983)	$V \propto \frac{1}{p}$	$PV = c$	$V \propto T$	$P \propto T$	$\frac{PV}{T} = c$		0	0	0
Cackett et al. (1983)	$P \propto T$	$V \propto T$	$P \propto \frac{1}{V}$	$PV = c$	$\frac{PV}{T} = c$		1	0	0
Williams et al. (1984)	$\frac{V}{T} = K$	$PV = c$	$\frac{PV}{T} = c$	$PV = nRT$			1	1	0
Panham & Webber (1984)	$P \propto \frac{1}{V}$	$V \propto T$	$V \propto \frac{T}{P}$	$\frac{PV}{T} = c$	$P \propto T$	$PV = vRT$	0	1	0

Note:

Note:

A $\Rightarrow$ 0 = Historical; 1 = Historical except V $\propto$ T precedes V $\propto$ $\frac{1}{P}$; 2 = Use of V $\propto$ n; 3 = Other

B $\Rightarrow$ 0 = Simple $\rightarrow$ Complex with no cognitive gaps; 1 = Simple $\rightarrow$ Complex with cognitive gaps; 2 = not simple $\rightarrow$ complex.

C $\Rightarrow$ 0 = Logical sequence; 1 = Not logical (Refer to Figures 1 and 3 for examples.)

Figure 2: Gas law sequence in fourteen physics textbooks used in Australian secondary schools

For sequence classification B, sequences which represent a simple to complex sequence with no cognitive gaps are coded B-0; sequences which are simple to complex but which contain cognitive gaps are coded B-1; and sequences which do not follow a simple to complex model are coded B-2. A simple law is regarded as one which more than likely indicates the relationship between two variables and a complex law as one indicating the relationship between three or more variables. A sequence which moves from $V \propto 1/P$ to $V \propto T/P$ by combining $V \propto 1/P$ and $V \propto T$ does not contain a cognitive gap between $V \propto 1/P$ and $V \propto T/P$ because of the presence of $V \propto T$. A sequence which moves from $PV/T = \text{constant}$ to $PV = nRT$ without considering either $P \propto n$ or $V \propto n$ is regarded as possessing a cognitive gap because it is not obvious that if $PV/T = R$ for 1 mole, then $PV = nRT$ for n moles. Examples of these codes for classification B are given in Figure 3.

For sequence classification C, sequences which have a logical progression are coded C-0 and those which are not logical are coded C-1. Logical sequences contain closely related laws in adjacent positions. For example, $V \propto T/P$ in a logical sequence would occur next to $PV/T = \text{constant}$

and $PV = \text{constant}$ would occur next to $P \propto 1/V$.

RESULTS OF THE STUDY

Textbook Analysis

Fourteen physics textbooks currently available for use in Australian secondary schools and selected by the authors were examined for the presentation of a gas law sequence and these sequences are recorded and coded in Figure 2. A summary of the comparison of gas law sequence categories A, B and C for physics textbooks is given in Figure 4.

All physics (100%) texts examined show a simple $\rightarrow$ complex sequential development of the gas laws in logical progression where closely related laws occur in adjacent positions in the sequence. However, none of the texts use the volume or pressure - moles relationship in the sequence, and only six of the texts consider the ideal gas equation $PV = nRT$, with the result that only about half of the texts use a simple $\rightarrow$ complex form with no cognitive gaps. The use of $V \propto n$ with $V \propto 1/P$ and $V \propto T$ for deriving $PV = nRT$ is a difference to the historical scheme (the historical scheme is used by a large number of physics texts) which would remove

the cognitive gap between $PV/T = \text{constant}$ and $PV = nRT$. Such a difference to the historical emergence may be considered beneficial to teaching and learning. The data in Table 1 show that a simple to complex sequence with no cognitive gaps is more than likely a logical sequence because textbooks tend to group related laws together. None of the physics texts use a sequence which is not simple to complex.

Teacher Reports

The mean and standard deviation for each item of science teachers' reporting of textbook dependence in Section 1 of the questionnaire are shown in Figure 5. Science teachers perceive a high level (> 5) of

B-0	B-1	B-2
$P \propto 1/V$ $V \propto T$ $V \propto T/P$ $V \propto n$ $V \propto nT/P$ $PV/nT = R$ $PV = nRT$	$V \propto 1/P$ $V \propto T$ $P \propto T$ $V \propto T/P$ $PV/T = c$ $PV = nRT$	$PV = nRT$

Figure 3: Examples of sequences under classification B where
 B-0 $\rightarrow$ simple to complex with no cognitive gaps;
 B-1 $\rightarrow$ simple to complex with cognitive gaps;
 B-2 $\rightarrow$ not simple to complex.

Factor	Textbooks	Teachers
A-0	42.9	6.8
A-1	50.0	2.9
A-2	0.0	88.4
A-3	7.1	1.9
B-0	57.1	72.8
B-1	42.9	3.9
B-2	0.0	23.3
C-0	100.0	62.5
C-1	0.0	31.7
C-2	0.0	5.8

Note:

- A $\Rightarrow$ 0 = Historical;
 1 = Historical except $V \propto T$ precedes $V \propto 1/P$;
 2 = Use of $V \propto n$;
 3 = Other
 B $\Rightarrow$ 0 = Simple $\rightarrow$ Complex with no cognitive gaps;
 1 = Simple $\rightarrow$ Complex with cognitive gaps;
 2 = not simple $\rightarrow$ complex
 C $\Rightarrow$ 0 = Logical;
 1 = Not logical;
 2 = not classifiable

Figure 4: A summary of the percentage of gas law sequences presented in physics textbooks ($n=14$) and reported by science teachers ($n=104$).

dependence on textbooks, particularly their current textbook, for content and student exercises (Items 1 and 6). In terms of the presentation sequence of the gas laws, teachers are likely to consult a number of different sources which may include the current textbook (Items 3, 4 and 5). However, it would appear that while teachers depend heavily on the current textbook for content and exercises they do not feel equally constrained to depend on a particular text for presentation style (Items 1, 3 and 6). In fact, the teachers indicate the use of a presentation style derived from a number of different sources which may not all be textbook sources (Items 3, 4 and 5).

The teachers' responses to Section 2 on gas law sequence used were coded using categories A, B and C as previously outlined. The percentages of teachers choosing the respective sequences are shown alongside the respective textbooks analysed in Figure 4. The majority of teachers report that they use a sequence which explicitly contains the $V \propto n$ relationship, which is simple to complex with no cognitive gaps, and which is logical. This is interesting when compared to the text analysis where many of the texts use an historical sequence which is simple to complex but which doesn't explicitly contain $V \propto n$.

Although a majority of teachers claimed to use a logical sequence, nearly 32% of teachers report using a sequence which is not logical. In comparison, all sequences shown in the textbooks were logical. It would appear that teachers are constrained to the textbook for basic content and exercises as shown previously but are not equally constrained when it comes to their approach to teaching about the gas laws. These results may indicate that some teachers are not relying on simple serial ordering of concepts in instruction but are using

Item	Mean	Standard Deviation
1. I choose the content from recent school textbooks (1960 to present)	6.44	2.16
2. I choose the content from old school textbooks (prior to 1960)	1.01	1.51
3. I endeavour to present the properties and laws in the same sequence in which they appear in the current school textbook	4.85	2.51
4. I endeavour to present the properties and laws in the same sequence in which they appear in a school textbook other than the current school textbook	1.57	1.63
5. I use a sequence for presenting the properties and laws of gases which I have developed from a number of different sources	5.08	2.40
6. I expect students to work through the exercises from the current school textbook	5.71	1.93
7. I use class exercises from sources other than school textbooks	4.83	1.96

Figure 5: Descriptive statistics from the questionnaire showing teachers' reports on textbook dependence of gas laws.

Notes: The items were scored on a scale from 0 (never) to 8 (always).
High values signify agreement with the statement.
Low values signify disagreement with the statement.

what Novak calls the psychological order which moves in a cyclic fashion through the conceptual hierarchy. This is an issue which warrants further investigation through teacher interviews and classroom presentation analysis.

CONCLUSION

In relation to textbook usage, this study has shown that teachers perceive a high level of dependence on the textbook for content and exercises but a lower level of dependence on a particular text with respect to teaching style. This teaching

style relates to the low usage of the historical sequence for the gas laws, the use of sequences which are simple to complex with no cognitive gaps, and the use by some teachers of sequences which are not logical. Since some teachers report the use of a sequence which is not simple to complex (23.3%) and the use of a sequence which is not logical (31.7%), a teaching style reflecting the Ausubelian cyclic use of a knowledge hierarchy may be present in some cases.

What can teachers learn from research of this nature? There are some trends in the data from this study which