ACID-BASE EQUILIBRIA, PART II: EFFECT OF DEVELOPMENTAL LEVEL AND DISEMBEDDING ABILITY ON STUDENTS' CONCEPTUAL UNDERSTANDING AND PROBLEM SOLVING ABILITY

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Abstract: This study examines the effect of two psychometric variables, developmental level (that is, general hypotheticodeductive reasoning ability), and disembedding ability or cognitive style (that is, degree of perceptual field dependence/independence) on twelfth-grade upper secondary students' ability to deal with conceptual understanding and chemical calculations. It was found that both variables played an important role in the performance of the students of our sample (N = 119). Disembedding ability had a clearly larger effect. Multiple regression analysis indicates that 28.3% of the variance of the performance in the whole test was due to the combined effect of the two psychometric variables. Developmental level was connected with most cases of concept understanding and application, but less so with situations involving complex conceptual situations and/or chemical calculations. On the other hand, disembedding ability was involved both in situations that required conceptual understanding alone, especially in demanding cases, or in combination with chemical calculations. Recommendations for instructions are made.

Key words: acid-base chemistry; acid-base equilibria; ionic equilibria, misconceptions; conceptual understanding, problem solving, developmental level, disembedding ability/cognitive style/degree of field dependence/independence

Introduction

In Part I of this work [1], twelfth-grade Greek students' misconceptions on acid-base chemistry were reported, with emphasis on acid-base equilibria. In part II we examine the effect of two important psychometric variables, developmental level and disembedding ability, on student performance in this area, and in particular their likely connection with the misconceptions students hold, the difficulties they experience, and their problem solving capability. Note that the connection of psychometric variables with concepts has received little attention in the literature so far. On the other hand, the importance as predictive variables of developmental level, information processing (working memory and/or mental capacity), and disembedding ability has been studied mainly in connection with science problem solving [2-7, and references therein]. (Note that calculations and problem solving are involved in several questions of the present study too.)

Developmental level [8], that is, general hypotheticodeductive reasoning ability, has been an important tool for concept analysis. Herron has widely applied Piagetian theory to chemistry instruction and chemical concepts. According to him [9]:

"Concepts that have perceptible examples and perceptible attributes, such as *solid* and *liquid*, may be thought of as concrete concepts. Concepts such as *element* and *compound* have perceptible examples but imperceptible attributes, while with *atom* and *molecule* both the examples and the attributes are imperceptible. Concepts that have imperceptible examples, imperceptible attributes, or both, might be regarded as formal concepts, ... that cannot be learned through direct, concrete experience. It is quite likely that they cannot be totally understood without some formal operational reasoning".

Shayer and Adey have also used Piagetian theory to categorize basic concepts of chemistry, physics, and biology [10]. Further, they have done extensive work for cognitive acceleration through the CASE project (Cognitive Acceleration through Science Education) [11].

Johnstone has used information processing theory in his analysis of chemistry concepts [12], distinguishing in chemistry three main components, the *macro*, the *sub-micro* and the *representational* [13]. While the chemistry teacher is thinking simultaneously at all three levels, it would be a mistake to imagine that all, or many, of our students can follow the teacher. Thus, to introduce the concepts of *element* and *compound* we are simultaneously having to use the sub-micro concepts of *atom* and *molecule,* and representing all this by *symbols, formulas* and *equations.* This new kind of concept takes a long time to grow, but once we have it embedded in long-term memory, we can use it as a powerful way of looking at the world [12].

Rationale

A great effort in science education research has been devoted during the past twenty years on students' conceptions that *differ significantly from what is socially agreed by the scientific community.* However, very little effort has been made toward connecting students' conceptions with various psychometric variables.

Some researchers maintain that there is a relationship between the Piagetian perspective and the alternative conceptions movement. As Carey has pointed out [14], Piaget and his collaborators have unveiled a great number of misconceptions children hold about the physical world. In addition, Marin and Benarroch [15] have compared empirical Piagetian and constructivist studies on the notion of force and on the notion of corpuscular nature of matter and found that Piaget has previously detected the majority of conceptions currently recognized by the alternative conceptions movement. On the other hand, Adey has refused to view the two programs as irreconcilable rivals and thinks it very likely that both programs will eventually be combined [16]. In addition, Niaz [17] has argued that the alternative conceptions movement at its present stage of development cannot explain the previous successes of the Piagetian School nor supersede it by a further display of *heuristic power* as required by Lakatos. (In Lakatosian terminology, there is no *progressive problemshift* between the two research programs.) Finally, Eckstein and Shemesh have provided mathematical evidence that supports a *stage theory of alternative conceptions,* which is related to the Piagetian stage theory [18].

Developmental level is an important predictor variable because most science concepts are based on hypotheticodeductive systems of scientific explanation (for a review, see [19]). The importance of hypotheticodeductive reasoning as compared with domain-specific knowledge has been a subject of considerable debate in the science education literature [20-23]. While domain-general reasoning is an important and frequently overlooked area of investigation [24], it is important to note that in later years, Piaget himself recognized the role of domain-specific knowledge in the acquisition of formal operational reasoning [25].

Finally, disembedding ability or cognitive style [26-28] represents the ability of students to disembed perceptual information (cognitive restructuring) in a variety of complex and potentially misleading instructional contexts [29-34]. Kitchener emphasized that it is essential that the developmental level of students be studied along with individual difference variables, such as Witkin's cognitive style (disembedding ability) [35].

Method

In order to investigate students' conceptions on acid-base equilibria, a questionnaire consisting of ten multiple-choice and eight open-type questions (in two forms A and B) was constructed and utilized. The questions were categorised in eight categories: a) dissociation and ionization, b) definition of Brønsted -Lowry acids and bases, c) ionic equilibria, d) neutralization, e) pH, f) buffer solutions, g) degree of ionization. Because the Lewis model is not included in the curriculum, the questions only referred to the Arrhenius and the Brønsted–Lowry models. The exact questionnaire plus further details about the validation and reliability of the test (including facility and discrimination values for each question), as well as the sample and the method of administration and of evaluation of students' answers have been given in Part I of this work [1].

Table 1 summarizes the content of the questions, and gives the performance on each question for the whole sample. We repeat that, despite the fact that many questions were demanding, performance was not low. This was due to the fact that our subjects were highly motivated and worked hard for the course, because it was crucial for their university entrance examinations. In four straightforward questions (2, 4, 9, and 10), performance was relatively high ($\geq 70\%$). On the other hand, the lowest percentage mean marks were: 41.7 (effect of temperature on pH), 41.0 (operation of common-ion effect), 40.1 [pH calculation of $H_2SO_4(aq)$], and 34.1 [pH calculation of $H_2SO_3(aq)$]

***Table 1:* Description of the questions of the test, plus percentage performance (means; standard deviations in parentheses) of the whole sample of students ($N = 119$).**

Dissociation and ionization		***pH (continued)***	
1	Dissociation versus ionization: 52.7 (49.9)	9	Means of changing pH: 69.8 (43.6)
Definition of Brψnsted-Lowry acids and bases		14	pH calculation in a diprotic acid (H_2SO_4): 40.1 (41.5)
2	Identification of Brψnsted-Lowry acids and bases: 71.5 (36.4)	18	pH calculation in a diprotic acid (H_2SO_3): 34.1 (34.4)
3	Species that act both as a Brψnsted-Lowry acid and base (amphiprotic substances): 46.4 (43.6)	***Buffer solutions***	
4	Identifying acid-base conjugate pairs: 80.3 (33.2)	10	Species of which aqueous solutions can behave as buffer solutions: 84.2 (31.0)
Ionic equilibria		12	Species of which aqueous solutions can behave as buffer solutions: 64.6 (47.8)
5	Species present in an aqueous solution of a soluble salt (CH_3COONa or NH_4Cl)]: 58.5 (30.3)	13	Effect on pH of adding various quantities of strong acids or base to a buffer solution): 50.4 (48.4)
6	Ionic equilibria occurring in an aqueous solution of a soluble in water salt: 49.0 (33.2)	17	Operation of common-ion effect: 41.2 (48.4)
Neutralisation		***Degree of ionization/dissociation***	
7	Stoichiometric amounts of strong base or acid required to neutralize strong and weak acids or bases respectively: 55.8 (41.8)	11	Degree of ionization of 0.1 M NH_3 or CH_3COOH aqueous solutions: 48.9 (48.5)
PH		15	Effect of temperature on pH (aqueous solutions with pH = 7 at 60 or 0°C): 41.6 (37.7)
8	pH of very dilute solutions of a strong acid or base: 59.1 (47.6)	16	Calculation of pH and degree of ionization of an aqueous solution of a weak acid or base: 49.1 (39.9)

Developmental level of students was assessed by means of Lawson's pencil-and-paper Test of Formal Reasoning [36], in its multiple-choice revised form (Test of Scientific Reasoning, [37]). From the 13-item multiple-choice test, items 7, 8 and 13 were deleted from the analysis because they were not parallel to items on other tests for developmental determination [38], including Lawson's intial test [36]. One point was given for each item for which a correct choice was made for both the basic question and the explanation. Students with scores 0-3 were classified as concrete operational; with scores between 4 and 6 as transitional; and with scores from to 7 to 10 points as formal operational. The mean score for the present sample was 6.67 (SD = 2.11). The reliability of the test was judged by means of Cronbach's coefficient alpha, which assumed the value 0.62 for our sample.

Cognitive style or disembedding ability is usually assessed by means of the Group Embedded Figures Test, GEFT) [27, 28, 39]. In this work, a similar test was used instead of the GEFT; this was a a timed (20 minutes) test which was devised and calibrated by El-Banna [40] from Witkin's original test materials, using hidden figures (the 'Hidden-Figures Test', HFT). The test has been used by the Johnstone group in all relevant work as well as in previous work of ours, and is assumed to provide an equivalent with GEFT measure of the degree of field dependence-independence. In HFT, students locate a hidden figure, which is embedded inside a complicated figure. Eighteen such items were given. Subjects with 13 or more successes were classified as field independent; with 7 to 12 successes as field intermediate; and with 6 or fewer successes as field dependent. The mean score for our sample was 8.70 (SD = 2.70), while a value of 0.69 was found for Cronbach's coefficient alpha.

Table 2 shows the distribution of students in developmental stages and levels of disembedding ability. It is noted that only a small proportion of students were at the concrete stage, while a relatively large proportion were at the formal stage. This finding does not agree with Shayer's data with the general British student population [41], and is explained if we take into account that the students of our sample were above average in ability as can be judged by their following the 'Positive Branch' of Greek upper secondary school system, a branch that leads to science, engineering and medical higher-education institutions. On the other hand, the majority of the students were found to be field intermediate, with only a small proportion being field independent. (Table 2 also shows the distribution of students into those who answered Forms A and B of the test used in the study. It is noted that students who answered the two forms were distributed in the same manner into the various psychometric levels, demonstrating equivalence of the two groups.)

Table 2*: Distribution of the students in developmental stages and levels of disembedding ability.

Developmental level				Disembedding ability			
	A	B	Total		A	B	Total
Concrete	5	4	9 (7.5%)	FD	13	12	25 (21.0%)
Transitional	21	20	41 (34.5%)	FInt	42	41	83 (69.7%)
Formal	26	24	69 (58.0%)	FI	6	5	11 (9.3%)

* The distribution of students into those who answered Forms A and B of the test used in the study is also shown.

RESULTS

Effect of developmental level

Table 3 has the performance of students in the questions according to developmental level. It is noteworthy that in most questions, the performance of concrete students was similar, and in some cases somehow higher than transitional students. This is surprising, and may be due to the small number (9) of concrete students in our sample. For this reason, we will pay not special attention to the performance of concrete students, but instead we will combine them with the transitional students, and proceed with the comparison of the formal students with the combined sample of concrete and transitional students. Table 3 includes the combination of concrete and transitional students, and the statistical comparison between the resulting two groups, through the values of the t statistic for independent samples. It is observed that in all cases performance of formal students was superior to that of the rest students, and in many cases (for 11 out of the 18 questions) this superiority was statistically significant. Statistical significant was also the superiority of the formal students in the whole test.

Table 3: **Percentage performance (means with standard deviations in parentheses) of students in the questions according to developmental level, and statistical comparison between [concrete (C) plus transitional (T)] and formal (F) students.[&]**

Question	C ($N = 9$)	T ($N = 41$)	C + T ($N = 50$)	F ($N = 69$)	t test value between (C+T) and F
1	32.5 (47.2)	55.8 (49.6)	51.6 (49.5)	53.5 (49.9)	-0.21 NS
2	68.8 (40.9)	62.3 (41.0)	63.5 (40.6)	77.5 (31.3)	-2.12 S
3	22.5 (34.3)	30.4 (41.1)	29.0 (39.8)	58.9 (41.7)	-3.94 S**
4	78.8 (34.3)	72.0 (36.7)	73.2 (36.0)	85.4 (29.6)	-2.02 S
5	53.2 (37.3)	44.3 (32.0)	45.9 (32.8)	67.8 (25.9)	-4.07 S**
6	38.6 (33.7)	39.0 (27.8)	38.9 (28.6)	56.4 (34.1)	-2.95 S*
7	43.2 (34.4)	46.9 (41.6)	46.2 (40.1)	62.7 (41.4)	-2.17 S
8	35.0 (46.0)	53.5 (47.4)	50.2 (47.2)	65.2 (46.8)	-1.72 NS
9	63.8 (39.4)	53.8 (47.4)	55.6 (45.9)	80.4 (38.3)	-3.21 S*
14	34.4 (35.6)	33.9 (40.2)	34.0 (39.1)	44.8 (42.3)	-1.42 NS
18	44.8 (34.0)	25.3 (29.4)	28.8 (30.8)	37.9 (36.0)	-1.44 NS
10	78.8 (34.3)	72.1 (38.3)	73.3 (37.4)	92.1 (21.9)	-4.01 S**
12	75.0 (41.6)	57.7 (49.6)	60.8 (48.3)	68.2 (46.6)	-0.84 NS
13	22.5 (41.6)	34.2 (43.4)	32.1 (42.9)	63.7 (46.5)	-3.78 S**
17	22.5 (41.6)	32.8 (45.0)	30.9 (44.2)	48.6 (49.6)	-2.01 S
11	20.0 (41.6)	47.2 (48.1)	42.3 (47.8)	53.5 (48.4)	-1.25 NS
15	23.8 (26.4)	32.9 (31.9)	31.3 (30.9)	49.1 (40.2)	-2.62 S*
16	37.8 (36.5)	45.0 (37.4)	43.7 (37.0)	53.0 (41.3)	-1.27 NS
Total [&&]	44.2 (10.0)	46.5 (17.8)	46.0 (16.7)	62.2 (19.7)	-4.71 S**

[&] S, S*, S** : statistically significant differences with $p < 0.05$, < 0.01, and < 0.001 respectively.
[&&] The total mark is based on the weighted participation of the questions as described in Part I [1].

Effect of disembedding ability

Table 4 has the performance of students in the questions according to disembedding ability. The Table also includes the results of statistical analysis for testing for significance of differences in performance between the three groups: values of the F statistic resulting from One-Way Analysis of Variance (ANOVA) for independent samples.

With the exception of question 1 (dissociation versus ionization), in all other questions the field intermediate students performed better than the field dependent ones. Using Scheffe's test for *post hoc* comparisons of means, we found that in 15 out of the 18 questions, this superiority was statistically significant. Similarly, in all questions (except question 2 on Brønsted-Lowry acids and bases, and question 8 on the pH of very dilute solutions of strong acids or bases), the field independent students performed better than the field intermediate students. However, because of the small number (11) of field independent students in our sample, we do not consider it appropriate to proceed to a comparison of means through Scheffe's test. The same pattern is also observed with the performance in the whole test.

***Table 4*: Percentage performance (means with standard deviations in parentheses) of students in the questions according to disembedding ability, and statistical multiple comparisons between [concrete (C) plus transitional (T)] and formal (F) students.**

Question	FD ($N = 25$)	FInt ($N = 83$)	FI ($N = 11$)	*F* statistic Value [&]
1	51.9 (50.0)	51.7 (50.0)	61.7 (48.1)	0.20 NS
2	42.0 (41.7)	79.5 (30.1)	78.3 (32.8)	12.62 S**
3	24.2 (35.0)	49.5 (43.6)	73.3 (39.1)	6.10 S*
4	53.8 (39.8)	86.7 (27.0)	91.7 (28.8)	12.24 S**
5	39.5 (32.6)	62.4 (27.4)	73.1 (22.8)	7.94 S**
6	22.4 (30.6)	53.6 (30.4)	74.0 (20.0)	14.90 S**
7	12.0 (20.3)	65.4 (38.3)	83.0 (32.6)	26.26 S**
8	39.9 (46.9)	64.3 (46.3)	65.0 (48.1)	2.73 NS
9	45.8 (48.8)	72.9 (41.3)	100.0 (0.0)	7.43 S*
14	18.1 (28.7)	42.2 (41.6)	75.8 (36.0)	8.80 S**
18	8.2 (20.3)	39.0 (34.1)	55.3 (30.1)	12.03 S**
10	54.2 (39.8)	91.0 (23.5)	100.0 (0.0)	20.25 S**
12	47.8 (50.0)	66.2 (47.3)	91.7 (28.8)	3.54 S
13	26.4 (40.3)	52.9 (48.1)	87.5 (30.9)	7.32 S**
17	1.9 (9.8)	50.0 (49.1)	65.0 (48.1)	13.33 S**
11	33.2 (44.1)	51.1 (49.1)	68.3 (44.1)	2.35 NS
15	15.8 (26.3)	47.1 (36.5)	60.0 (41.7)	9.26 S**
16	19.5 (28.3)	54.8 (39.2)	73.3 (33.4)	11.51 S**
Total [#]	30.9 (9.9)	60.0 (16.3)	76.5 (14.0)	48.14 S**

[&] S, S*, S** : statistically significant differences with $p < 0.05$, < 0.01, and < 0.001 respectively.

[&] The total mark is based on the weighted participation of the questions as described in Part I [1].

Combined Effect of the Two Psychometric Variables - Multiple Regressional Analysis

It is apparent from the results so far that both developmental level and disembedding ability played an important role in the performance of the students of our sample. It is also clear that disembedding ability had a clearly larger effect. To examine further the combined effect on performance on the whole test of the two psychometric variables, we carried out a multiple regression analysis with the perfomance in the Lawson Test and the "hidden figures test" (HFT) as independent variables. Note that performance on the whole test was derived from weighting the various questions as explained in Part I. The standardized regression coefficients *beta* were 0.192 for developmental level, and 0.443 for disembedding ability, both statistical significant at $p < 0.05$ and $p < 0.001$ respectively. On the other hand, the Pearson correlation coefficients between performance in the whole test and the two psychometric variables were 0.323 and 0.499 respectively. From these data, the coefficient R^2 of multiple correlation is calculated [42]:

$$R^2 = (0.192)\times(0.323) + (0.443)\times(0.499) = 0.062 + 0.221 = 0.283$$

This indicates that 28.3% of the variance of the performance in the whole test correlates to the combined effects of developmental level and disembedding ability, and this demonstrates the importance of these variables. Further, one is tempted to decompose R^2 into the relative contributions of the two psychometric variables: 6.2% from developmental level and 22.1% from disembedding ability, demonstrating that of the two variables, as measured with the used tests, disembedding ability seems much more important. Note that this decomposition is reliable only if the two independent variables have a zero or near zero intercorrelation [42]. In our case the correlation, though not high, is not near zero (Pearson correlation coefficient = 0.294).

Discussion and Recommendations

The highest effect of developmental level was observed in the case of the following questions: question 5 [species present in an aqueous solution of a soluble salt (CH_3COONa or NH_4Cl)]); question 10 (species of which aqueous solutions can behave as buffer solutions); question 3 [species that act both as a Brønsted-Lowry acid and base (amphiprotic substances)]; question 13 (effect on pH of adding various quantities of strong acids or base to a buffer solution). We observe that all these questions are conceptual. In the following questions, the effect of developmental level was not found statistically significant: question 1 (dissociation versus ionization); question 12 (species of which aqueous solutions can behave as buffer solutions); question 11 (degree of ionization of 0.1 M NH_3 or CH_3COOH aqueous solutions); question 16 (calculation of pH and degree of ionization of an aqueous solution of a weak acid or base); question 14 (calculation in a diprotic acid (H_2SO_4); question 18 (pH calculation in a diprotic acid (H_2SO_3); question 8 (pH of very dilute solutions of a strong acid or base). Here we have mostly questions that require performance of chemical calculations in addition to conceptual understanding. In conclusion, developmental level related with most cases of concept understanding and application, but less with situations involving complex conceptual situations and/or chemical calculations.

For twelve of the questions, the effect of disembedding ability was very strong: question 7 (stoichiometric amounts of strong base or acid required to neutralize strong and weak acids or bases respectively); question 10 (species of which aqueous solutions can behave as buffer solutions); question 6 (ionic equilibria occurring in an aqueous solution of a soluble in water salt); question 17 (operation of common-ion effect); question 4 (identification of acid-base conjugate pairs); question 2 (identification of Brønsted-Lowry acids and bases); question 18 (pH calculation in H_2SO_3); question 16 (calculation of pH and degree of ionization of an aqueous solution of a weak acid or base); question 15 (effect of temperature on pH); question 14 (pH calculation in H_2SO_4); question 5 [species present in an aqueous solution of a soluble salt (CH_3COONa or NH_4Cl)]; question 13 (effect on pH of adding various quantities of strong acids or base to a buffer solution). Finally, disembedding ability did not relate apparently only in one case: question 1 (dissociation versus ionization); this question is a special case, which despite not being cognitively demanding, it causes a serious misconception, which is related to the history of chemistry (see Part 1). In two other cases [question 11 (degree of ionization of 0.1 M NH_3 or CH_3COOH aqueous solutions; and question 8 (pH of very dilute solutions of a strong acid or base)], where we had not statistical significant F values, there was still a similar trend. It is apparent that disembedding ability is involved in most situations that require conceptual understanding alone, especially in demanding cases, or in combination with chemical calculations.

Relevant to our findings are previous studies. In previous work of ours, which dealt with the effect of psychometric variables on chemical (molecular) equilibrium problem solving [3], it was found that developmental level played the most important role, especially as the logical structure of the problem increased, while disembedding ability had a smaller effect. This finding was mainly attributed to the fact that the problems were rather algorithmic exercises for the students, because of familiarity and training. In another study with not well-practiced organic-synthesis problems [4], we found that field-independent and field intermediate students had an advantage over field-dependent students. Finally, we should consider that in the present study we had some calculations that involved either situations where misconceptions are involved (e.g. stoichiometric amounts of strong base or acid required to neutralize strong and weak acids or bases respectively) or unfamiliar problems (pH calculation in H_2SO_4 and in H_2SO_3; calculation of pH and degree of ionization of an aqueous solution of a weak acid or base; effect of temperature on pH).

Frazer and Sleet [43] reported that students solving multiple-choice chemistry problems often were unsuccessful at problems requiring more complicated logic even though they could solve several less complicated subproblems. Similar observations using free-response questions were reported by Lazonby, Morris, and Waddington [44]. Camacho and Good [45] studied the problem-solving behaviors of experts and novices engaged in solving chemical-equilibrium problems, and reported that unsuccessful subjects had many knowledge gaps and misconceptions about chemical equilibrium. Gabel, Sherwood, and Enochs [46] reported that their subjects used algorithmic methods without understanding the concepts upon which the problems were based. Niaz [47] compared student performance on conceptual and computational problems of chemical equilibrium, and reported that students who performed better on problems requiring conceptual understanding also performed significantly better on problems requiring manipulation of data, that is, computational problems; he further suggested that solving computational problems before conceptual problems would be more conducive to learning. Finally, Lawton [48] and Niaz [49] have shown that the manipulation of the perceptual field effect (disembedding/cognitive style) of proportional reasoning tasks changes student performance significantly.

In conclusion, one may ask why misconceptions and difficulties in dealing with demanding conceptual or/and calculational chemical questions exist and what causes them. Although incorrect, imprecise or incomplete teaching may play an important part (especially for the conscientious and diligent student who accepts as correct whatever the teacher teaches), there must be more fundamental reasons that cause misconceptions and difficulties. In this study, we have found that low disembedding ability and the inability of students to employ formal operations play an important role. Other psychological and cognitive factors may play a role too; such factors are: the information processing demand of the tasks and the information processing capacity of the students; the lack of the proper knowledge corpus which is a prerequisite for meaningful learning according to Ausubel's theory or the absence of the relevant concepts from long-term memory, resulting in rote application of definitions and algorithms; confusion caused by differences in language usage in everyday and scientific contexts; use of multiple definitions and models (e.g. Arrhenius' and Brønsted-Lowry's models)[50].

Turning to recommendations, attention should be concentrated to the misconceptions and those parts of the logical structure that resist change more strongly and hence constitute the 'hard core' [51] of students' understanding. Teaching strategies should be designed that can facilitate conceptual understanding (beyond the algorithmic strategies) based on the manipulation of the logical structure, and the perceptual field effect of tasks (problems and situations) involving acid-base equilibria. We can facilitate student success by introducing first problems and situations of simpler logical structure, leaving for later more complicated and demanding cases, when the students have acquired experience and motivation. In this way, confidence can be maintained while complexity increases, leading novices towards the expert state. In general, the emphasis in instruction should be moved away from learning to use complex algorithms, into activities that require higher-order cognitive skills, such as concept understanding, critical thinking, and genuine problem solving [50]. Educational interventions that aim to accelerate cognitive development through science education, such as the CASE project [10] are considered as effective too. Last but not least, new methods, especially constructivist teaching and learning, used from the first stages of education, are promising to contribute to the above goals. Methodologies such as the proposed above are expected to improve disembedding ability too. Needless to add, that teachers must apply new methods consistently.

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