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A study of seventh grade students' explanations of phenomena in an enquiry oriented biology laboratory.

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Enquiry processes were used for promoting students' ability to identify phenomena in their surroundings, and to explain them on the microlevel by employing knowledge of physical forces.

Explaining a new phenomenon involves the ability to retrieve relevant stored knowledge and to activate this knowledge by cues present in the new situation. Being able to fit the new situation into a general schema enables the generation of conclusions that are not already stored (Prawat, 1989; Stillings et al., 1987). The similarity of the retrieval cue to the original context influences the cue's effectiveness in enhancing recall (Reed, 1992). Detecting the cue (signal) enables a more effective retrieval strategy, but may also result in an error caused by not recognizing the signal (a miss), or recognizing it when it is not there (false alarm). A signal possessing a larger familiarity value has a better chance of being recognized. Findings indicate that students were better able to apply an analogy while problem solving when they were informed that the analogy was relevant, and when familiar content enhanced their ability to reason (Reed, 1992). While learning, students store both the content studied and the contextual information associated with it and concerned with its meaning. Such information helps in remembering later on. Improved comprehension improves recall (Reed, 1992).

Meaningful learning results not by storage alone, but by the appropriate linking of new knowledge to prior knowledge that may or may not be consistent with the scientific notions being studied or observed, and that may interfere with its comprehension (Roth, 1986). Such prior knowledge in the case of learning science includes preconceptions of students. These preconceptions persist due to their great explanatory power of the everyday world, and therefore actively compete with the scientific alternatives. Learning must involve modification or replacement of students prior conceptions with appropriate alternatives. Among strategies suggested is to expose students to an event, sharpen their awareness to alternative conceptions through discussion and debate, have students explain a conceptual conflict, and guide students to accommodate a new concept consistent with the scientific one (Smith & Lott, 1983). Although the present study is not concerned directly with misconceptions, they do exist and play an important role in the ability of students to explain phenomena. The misconceptions of matter and molecules (what is between them, how they move, etc.) that students have are described in the literature (Lee, Eichinger, Anderson, Berkheimer & Blakeslee, 1990), and were identified in the present study as influencing the students' ability to explain a situation.

The more new information is integrated with old information, the better the ability to transfer and use it in a variety of contexts. The better it is organized (categorized and hierarchical) in the cognitive structure, the easier it is to be identified (Prawat, 1989; Voss, 1987). Spontaneous transfer seldom occurs. It depends partially on the amount of practice and the variability of context. Learning to transfer knowledge requires not only practicing but also talking about the procedures and concepts, developing reflective awareness, and articulating one's own thoughts. Discussions make students more aware of what they know or do not know, and confrontations with alternative views expose students to the limitations in their own thinking. (McKeachie, 1987; Prawat, 1989). It is desirable to make the shift from context dependent knowledge use (situated learning) to a more context free generalization of the use of knowledge (Leinhardt, 1990; Pea, 1987), balancing between generalizability and specificity while teaching (Prawat, 1989).

The present study was an examination of an enquiry oriented biology course for seventh-graders. The objectives of the course were (a) to enable students to acquire the procedural knowledge of enquiry; (b) to promote students' ability to recognize cues in the phenomena they enquire about, and to use these cues in the retrieval of the knowledge required to explain the situation; (c) to facilitate students' ability to explain phenomena on the microlevel using knowledge acquired; and (d) to assess students difficulties in interpreting new situations in the aim of designing a better instruction strategy.

METHOD

Subjects

The study was carried out in the seventh grade of an Israeli junior high school, where most of the students are from medium to high socioeconomic backgrounds. Less than twenty five percents of the students are from low socioeconomic backgrounds, admitted to school as part of an integration plan. Out of four equally constructed seventh grade classes, one was randomly chosen for the investigation. The class comprised thirty-six students between the ages of twelve and thirteen and a half. Grade distribution was normal. Seventh grade, the first grade in the Israeli junior high school, is where students first encounter a university graduate biology teacher, and the orientation of scientific enquiry.

Apparatus

Simple materials and equipment (such as capillary tubes, test tubes, measuring vessel, various liquids and granularic solids, plants, etc.) were used to conduct both the open ended enquiry and the demonstration of the physical forces involved.

Procedure

The study was designed to investigate the research findings of knowledge construction, retrieving, and applying as discussed in the background section. The investigation consisted of several phases, each comprised of a routine of three modes of learning: individually, in groups, and in a class setting (order varied across phases). Activities in each learning arrangement varied and included hands on activities, demonstrations, conferences and discussions. Such modes of learning enable the promotion of knowledge processing and construction by interaction among learners (presenting individual ideas, having to explain them to others, and defending them from being discarded as incorrect), and by the relating of newly acquired knowledge to prior existing knowledge. Thus in phase 1 of the study, when students tried for the first time to plan and conduct an experiment, they started by performing it in a group setting, continued with the individual task of describing the experiment (writing a scientific report), followed by a class discussion that summarized, clarified, and elaborated on the phase content. In a later phase, when the physical forces were already known and had to be used for explaining a new phenomena, an opposite strategy was employed: each student explained the phenomena working alone, and than continued by presenting the ideas and conclusions to the whole group for further refining and final report. Class discussion revealed the holistic view of the phenomenon studied and presented examples for its possible application.

The students were divided into six homogeneous groups A to F, according to grades and teachers' recommendation regarding students' abilities. In spite of the similarity within groups, a range of personal differences existed among the group members due to their diverse abilities, prior knowledge, prior experiences, and so on. Learning in homogeneous groups enabled all students to employ their full potential without being discouraged by better students. Group A comprised the best students while Group F comprised the lowest achievers of the class. (The labels A to F were used for the study only). Intergroup mobility was possible according to students' performance. Two students exchanged groups in the course of the study.

The study lasted for five months. Students studied five biology hours per week (two plus three) to allow the time required for planning, conducting, and debating the situations, experiments and topics studied. Only part of the lessons in the course were allocated for learning the issues concerning this study. Those lessons were spread in time, separated by the routine biology studies. In the course of learning a variety of topics, students exercised the process of scientific enquiry and of employing an active search of their mind, reviewing all information acquired in the course, in order to arrive at the relevant one to be used in explaining a new phenomenon. Such a procedure reduced the chance of students automatically using the last information acquired.

Description of phases

Phase 1: Students studied and practiced (hands-on activities) the process of scientific enquiry. In order to assess the learning products of this phase, each group of students was presented with a set of simple materials and lab equipment, and was required to formulate a research question, design and carry out an experiment accordingly, and hand in a written report including notes, ideas, and conclusions jointly agreed upon. Later on each student reported individually on the same experiment. Class discussion summarized the experiments, revealed the physical forces that explained the phenomena described, identified the specific conditions in which these forces act, and related it to students' every day experiences. Teacher-student interaction emphasized the similarity between the situations encountered.

Phase 2: Students were required to explain a new phenomena based on the same physical forces studied previously. In spite of the novelty of the situation, this phase contained clearly observed elements already encountered in phase 1, which could be used as cues for identifying the relevant knowledge to be employed for the new explanation. They first completed the task individually, and then continued in a group setting arriving at a final explanation accepted by all, followed by a class discussion. In order to asses the ability of all members in each group to follow and understand their group discussions, and to change their own ideas accordingly, all students were asked to individually explain the phenomenon in their words as a home assignment.

Phase 3: Each student was asked to observe the surroundings of home, identify any phenomena based on the physical forces presently learned, and describe, explain, and report it in detailed written form. The cue that triggered the students' selection of phenomena could be explicit (as in phase 2) or tacit.

Phase 4: Students were presented with a situation that involved the same forces studied previously, but acting in a new context thus demanding a generalization of the identifying cue. A test was administered examining students' abilities to perform and explain the new experiment. Students reported on the experiment individually and then jointly with the group. A class summary followed.

Phase 4 was added due to the findings that phase 3 was very difficult. An intermediate phase was required between being exposed to a clearly observed identifying cue and the ability to discover a tacit one.

Investigations carried out in the first phase included: a) water holding capacity of different size granular solids (earth, sand, and gypsum), b) various liquid rise in a capillary tube, and c) coloration of flower plant kept in colored solution. It was assumed that an experiment planned, discussed, and performed by the students would be more relevant and meaningful to them than one they have to carry out as a given recipe. On the other hand, the materials and equipment students received did not allow for a wide range of possibilities.

The test administered in the second phase involved a simple chromatography of a drop of dry blue ink. Students' task was to observe the phenomenon until no further changes could be noticed, and then explain it.

The fourth phase demanded each student's detailed explanation for the difference found in the number of drops of both water and soap solution counted in a constant volume.

The basic physical forces discussed were adhesion, cohesion, and, more generally, gravitation and air pressure. In addition to describing and explaining the cases mentioned above, many other examples of every day phenomena, raised by the students, were demonstrated and analyzed; for example, the mixing of water and oil, or the behavior of mercury as seen when the thermometer breaks. All cases involved liquids.

Students handed the teacher their written assignments upon the completion of each step in every phase, so no changes could be made in the reports of a previous step.

A thin grain content analysis technique was employed for the interpretation of the learning process. All collected written assignments for each step of the phases (both the individual and the groups' ones, written homework concerning the relevant issues, the administered tests, and notes of the lessons' verbal interaction) were analyzed. Individual reports were compared with group reports. Some episodes were audio and video-recorded.

Note: The concept of ”meaningful understanding” is used in the present study to describe the ability to use newly or previously acquired knowledge in many diverse situations, due to the organization and interconnectedness of the informational elements that comprise this knowledge.
Note: Within the scope of the present study, only the results concerning the issue of explaining phenomena will be addressed. Other issues will be reported in detail elsewhere.

RESULTS AND DISCUSSION

The thin grain analysis performed on all products of every phase of the study revealed some enduring factors affecting students' ability to explain biological and physical phenomena. The examples reported here are characteristic representatives of products of the learning processes investigated in the present study.

1. Students' verbal ability

Low achievers frequently displayed difficulties in expressing their ideas, especially in a written form. Sentences were formulated ambiguously, including unclear themes, various parts losing their meaning, and vague descriptions unrelated to other parts. For example, a low achieving student wrote ”...the sand is absorbed” meaning to say that the rain water was absorbed in the sand; ”...the flowers raised” meaning that the color rose to the flowers; ”....The water molecules are strong” meaning the cohesion forces between the molecules was strong.

Deficiency in verbal ability may either conceal student understanding, or elusively make others believe a student understands, when he/she does not, which disrupts the learning process. One of the results is an erroneous categorizing of information acquired that damages students' ability to search for that information in the future.

2. Conducting an enquiry

Some major differences were found between high and low achievers concerning their performance in carrying out and reporting an enquiry. Better students exhibited accurate procession through the hierarchical stages of the scientific enquiry, each step logically followed from the previous one: An observation was stated, from which a question was drawn, leading to an hypothesis that presented a possible logical answer to that question, planning an experiment to prove (or disprove) the hypothesis, stating results in an organized and scientific manner, and drawing conclusions. The experiment itself included one well-defined dependent variable, a planned control, and rehearsals. Low achievers reports of the enquiry they conducted usually lacked such logical and accurate processing; stages were verbally formulated in a non-consistent manner, and various stages were skipped (control, rehearsal, conclusions).

The following example demonstrates the above properties by citing two individual reports of an high and a low achiever, written in phase 1 after group discussion. Words were underlined to emphasize a continuity of thought along the enquiry stages.

High achiever's report

Observation: "Standing on the shore it started raining and water was absorbed into the sand".
Question: "What is the quantity of water that was absorbed in various granularic solids"?
Hypothesis: "The thinner the texture of the solid the less water it absorbs".
Experiment: "Take 100 ml of water and pour it into the 100 gr of sand in the vessel.
Control: "Repeat the same experiment varying the dependent variable (type of solid). Earth and gypsum will be used this time".
Rehearsals: "It is advised to carry out several sets of experiments simultaneously, to make sure the measured results are accurate".
Results: Arranged in a table containing the following columns: Material, Quantity of water added, % of water absorbed.
Conclusion: "The thinner the texture, the smaller the power of absorption. The reason may be the fact that small granules leave little space for water between them so the water penetrates the ground".

Low achiever's report

Observation: "We took five test tubes, two blue, two red, and one containing water. We got a jar of flowers, a razor, and scissors".
Question: "What is the influence of the flower on the liquid"?
Hypothesis: "The stem of the flower will absorb the color of the liquid".
Experiment : "We will examine: a stem with a flower, a flower without a stem, a flower with a shaven stem, flower sepal, shaven sepal, a flower cut at the edge".
Control : None
Rehearsals : None
Results : Arranged in a table containing the following columns: The flower (a stem, flower without a stem, flower with shaven stem, cut sepal), In red liquid (absorbed red, no influence, the flower absorbed a bit of red, the flower rose), In blue liquid (the same as red).
Conclusion: None

The properties mentioned above as characterizing a good enquiry process are lacking in the low achiever student's report. Deficiency in verbal ability causes the meaning of sentences to change. (e.g. "two blue" meant to be two containing blue liquids; other examples were specified earlier). The observation describes the equipment, rather than an observation. The question asked should have led to a different experiment than the present one. According to the experiment suggested and carried out by the student, the question asked should have been "What is the influence of the colored liquids on the different parts of the plant treated in various ways?" But as suggested, the student examined three dependent variables at the same time, a) the type of color liquid, b) the part of the plant and c) the treatment it received. The hypothesis deals with the stem only, and is not an answer for either of the suggestions. The experiment proposed for answering the research question deals with all different parts of the plant (not the stem only) treated in various ways. It does not describe what will be done with the parts suggested for the experiment. Such an experiment is not able to answer any question unambiguously due to the lack of control and rehearsals. The general idea of the table and the columns in it are correct; except for the use of the word "flower" instead of plant, and the fact that the reported parts of the plants and treatment used are different again from those mentioned in the question, the hypothesis, and the experiment. The lack of organized, logical, and consistent thought, is salient, and affect students' ability to explain phenomena; it repeated itself through out the investigation.

Other indicators for a greater ability to manipulate and use knowledge are the manner students explain the results obtained, their ability to translate information from one form to another, and the way they discard irrelevant and unimportant details for the sake of addressing and presenting the major ideas. Better students utilized (correctly or incorrectly) their prior knowledge, generally acquired at school. Low achievers did not. This fact indicates more connections between concepts of diverse categories and better organization (categorization and hierarchy) of information in the cognitive structure (e.g., the use of the concept of "texture" was borrowed from geography, or the use of prior knowledge that water infiltrates sand easily). Low achievers gave very detailed descriptions for each step of the enquiry. Most of the details were not required and caused confusion by concealing the major variables and ideas. For example, in another experiment, factors that should have been reported in the description of the experiment (as they ware equal for all cases) were reported repeatedly in separate columns. Low achievers used the original presentation as is, while better students exhibited the ability to translate information and make sense of the results obtained (e.g., measuring in ml water and reporting results in %).

We should note that better students too had difficulties interpreting the results. They based their interpretation on a mechanical perception of the situation (smaller granules, smaller space for water, less water absorbed) ignoring any forces acting in it.

3. <u>Group report versus individual report</u>.

Phase 1: Group reports preceded individual reports.

Comparing the reports yielded the following findings: (a) For groups comprising successful students: the better the students in the group, the more diverse was their formulation of individual reports compared to the joint report. Reports of less successful learners of the same group (who still represented good students) were more similar to the shared report, exhibiting small differences in words or in sentence construction. (b) For groups comprising the unsuccessful learners: individual reports contained the main ideas of the joint report, but were more distinct from each other than those of the best students. Here, too, the better the student, the more diverse was the individual report compared to the joint report. These differences between the individual and the joint reports suggest a difference in their writing ability and learning process.

Following are examples demonstrating the reported results:

1. Group A: The experiment of water absorption by various solids.

<u>Joint report</u>	<u>Individual report</u>
Posing a research question	
	Best student
"Are different amounts of water absorbed in different kinds of grounds"? (initially included: because of texture, but then decided to include this in the hypothesis).	"Will the absorption of water in different grounds be equal"?
	Less successful student
	"What are the amounts of water in different grounds of various textures"?
Conclusions	
	Best students
"A thinner texture has a	"Different kinds of earth absorb different quantities of water."

lower absorption power because the grains are closer together and there is no place for water".

"In thin texture less water is absorbed, in thick texture more water is absorbed because there is a wide space for water between the grains. The water combines with the grains to become one bulk".

Less successful student

"In a thinner texture the absorption power is lower because the grains are closer together and the water has no space to stay in, so they penetrate the ground."

2. Group F: The experiment involving flowers in colored liquids.

Posing a research question

"How do the liquids influence the flowers?"

Better student

"How will the liquids influence the flower/plants?"

Less successful student

"What is the influence of the flower on the liquid?"

Raising an hypothesis

"The color will be absorbed in the stems."

Better student

"The plant will obtain the color of the liquid in which it soaked after a long time".

Less successful student

"The stem of the plant will absorb the color of the liquid".

Analysis of Phase 1 reports

Group A: When the group posed the research question, they discarded the part of the sentence that said "because of different texture", keeping it for future use in the hypothesis. In spite of that fact, the less successful student continued to use this part in the research question, probably because he did not understand why the group discarded it at that point of the enquiry report. His own question was not a direct outcome of his observation. This student, although using the same words used by his group while posing the research question, changed the meaning of the question. The better student was capable of formulating the question in his own words while keeping its meaning intact.

The better students used the ideas from the group but stated them differently to fit the rest of the stages of their enquiry. One of them generalized the group conclusions to fit his question and hypothesis. The other elaborated on the conclusions, adding to it a new dimension by mentioning the bulk of earth (which was an important observation). The less successful student stuck to the group conclusions, adding only the idea of the water penetrating the ground, which was not new, self-produced information, but rather the same claim (water has no space) in different words.

Groups F: It seems that group discussions helped these students to increase their ability to express their ideas to others, and thus to better organize and defend their own thoughts. Still, they found it very difficult to follow and understand each others ideas of what to do, why, and how, presented in an unclear manner. So the major, basic views were kept by all, but integrated in various individual frameworks of minds based on prior knowledge and experiences.

Although both students cited here were generally unsuccessful learners, it seems from analyzing their reports that the one cited first has more understanding of the ideas reported by her. The answers of the other student (cited second) seem to be the result of a low verbal ability and a difficulty in trying to memorize the group ideas due to the lack of meaningful understanding of the ideas. She memorized the general idea her group raised, but stated it the other way around, which would have changed the course of enquiry completely. Because she did not understand that, she went on pursuing what the rest of her group did, even though it did not fit her own line of thought. The hypothesis reported in this phase, clearly present the notion that the better student was more capable of deviating correctly from the group format.

Phase 2 and 4: Individual reports preceded group reports.

Comparing the individual with the group reports in both phases 2 and 4, yielded similar findings. The following examples are from phase 4 only. It should be emphasized that the concept of surface tension was not addressed in the course of study. Group report was always better formulated, better explained, and more accurate than the individual ones. It seems that group members wisely judged what information reported by individuals should be included or discarded, and what new information constructed by the group as a whole should be added. Why students chose a specific joint answer from all responses raised in the group should be addressed separately. Possible factors involved are the academic status of the student whose answer is considered, how well this answer is presented by the student, how much logic and sense it makes to the others, how relevant and close it is to their answer, and so on.

We will now compare individual and joint reports across the range of student abilities (Groups A, C, and F).

Group A: Individual reports

1. "Soap drops are smaller than water drops because the cohesion forces in them are weak. For the same reason, smaller drops of soap are pushed out of the dropper by the air pressure (formed by pressing the dropper) and soap solution molecules hardly pull other molecules behind. The water is a bit more dense. It is also possible that adhesion forces are stronger between the water and the glass tube, allowing more molecules of water to accumulate in the drop before it breaks off the tube to form a larger drop. Another possibility is that water is lighter than soap, therefore pulled less strongly by gravity."

2. "As can be noticed from the results, the same volume in the dropper contains less drops of water. It means that each drop was bigger. Soap had a double number of drops, therefore each drop was smaller. This could be the result of the fact that cohesion forces in the water are stronger than when soap is added. It means that soap decreases the cohesion forces between the water molecules and separates them to be further apart. It is also possible that the weight of the two solutions is different."

3. "Water molecules are further apart from each other because cohesion forces are weaker than in soap solution. Therefore, there are more water drops in the same volume and they are smaller. Adhesion forces between the soap and the water are strong, which explains the fact that soap has less drops but larger in the same volume compared to water. Gravity overcomes the forces of cohesion and adhesion easier in water, where they are weaker, thus forming small drops".

4. "There is a difference in the number of drops because the water is more dense and the soap is more diluted. The composition is different. It is possible that the volume of soap is different than the volume of water. When we made a drop of water fall, we released pressure and probably activated more energy than when we pushed the soap solution. Because the soap comprises both water and soap, its composition is more diluted".

Group A: Joint report (the numbers in the parenthesis indicate ideas in individual reports).

"Cohesion forces in water alone are greater than those that exist in water to which soap is added (1,2,3). Soap weakens cohesion between water molecules and thus creates smaller drops in soap solution (2,3). The soap solution is more diluted than water (1,4), therefore the drops are smaller and they exceed the number of water drops in an equal volume (1,2,3). The adhesion forces between the water and the dropper (1,3) cause the accumulation of molecules when they fall (1)".

Analysis of group A reports

All successful students started their thinking process by analyzing the results they obtained. Their line of logic was that if there are more drops in the same volume, each must be smaller, and due to weaker cohesion (adhesion) forces, gravitation pulls the drop downward and overcomes more easily these forces by causing molecules to break off from the rest of the molecules in the liquid.

The third answer is of interest. The interpretation given is perfect except that water is exchanged with soap. Looking into why and how it happened, it was noted that the results obtained by this student was the opposite to the rest of the class (about half the soap drops compared to water drops). A checkup of the sets of experiments used in the exam revealed that the labels on the bottles of water and of soap were mixed. This incident proves that the student's idea originated from the results and not from preconceived notions.

The fourth report was given by the lowest achiever in the group. She studied hard and was considered by all teachers to be a good student. But a thin grain analysis of her answers at times indicated a process of learning by memorization more than by meaningful understanding. For her the group setting was an ideal arrangement, enabling her to follow group discussions, write them down, learn and understand them at home, and thus remain on top of things at all times. Unlike other group members, her answer originated from an intuitive notion that "water is denser than soap" and not from the results obtained. The soap solution was considered to be diluted because it contained both water and soap molecules, so the water was no longer dense but diluted by the soap molecules. Pure water was dense because it was not diluted by the soap. Water was considered to be the dissolved matter, not the solvent. Not using the given data (that the volumes of the liquid examined were constant), the student arrived at the wrong assumption that "volume of soap is different than volume of water" instead of relating the volume to the numbers of drops. This may also be the result of deficiency in verbal ability to express ones ideas clearly. She could have meant the volume (or size) of a drop like other group members. There are hints that the correct ideas were starting to crystallize, but they cannot yet be considered as correct responses. Stating that more energy needs to be invested in pushing a water drop than pushing a soap solution drop may indicate an intuitive understanding that cohesion is stronger between water molecules. (It should be noted that this student also wrote the observation that the "...the sand was absorbed".

The joint report presents ideas of all group members, as displayed by the number of the students' responses in the parentheses. The answer is formulated clearly. Details the group was not sure of, or had no proof for, were discarded; such as the idea (4) of more energy being invested in pushing the drop of the water. Other ideas were corrected according to the majority (3). They accepted the idea that the soap solution was more diluted than water, but gave it a completely different interpretation than the one given in the fourth report. It seems that, for this group, being diluted meant having less molecules per volume unit due to decreased cohesion forces between them.

Group C: Individual reports

1. "The soap drops were smaller than the water drops, smaller each time I pressed the dropper. The molecules in the soap were denser, therefore the adhesion/cohesion forces acting on them

increased and each drop decreased in size, because out of the tiny opening of the dropper only a small quantity of dense liquid may get out. The water was less dense therefore the amount going out of the opening could be larger".

2. "Soap solution is denser than water, therefore there are more drops of it than of the water that is more diluted. This is derived from the fact that a solid mixed in water will be denser. Such a situation demands more energy in order to push the matter out, so we press the dropper more times. Since we press with the same amount of energy, the water that is less dense will get out in larger amounts and less number of presses".

3. "The drops of the soaps are bigger. The soap solution contains more components, both water and soap. The soap is heavier than the water and more complex, and that is why when we take out the soap only small parts of it get out each time".

Group C: Joint report (a + indicates new information not found in the individual reports).

"Each press is equal to the others regarding the amount of energy invested in it (2). Therefore the soap solution, the denser liquid (1,2,3), requires more presses for pushing it out of the dropper (1,2). More presses means more energy. The soap solution contains both water and soap. There are cohesion forces in the water and in the soap (+). There are adhesion forces between the water and soap molecules (+). Since the soap solution is denser, a smaller quantity of it can get out of the tiny opening of the dropper (1,2,3)".

Analysis of group C reports

Many baseless assumptions and misconceptions that are treated like facts are raised by the members of this group and lead them to the wrong conclusions: the molecules are denser so the forces increase (meaning the student regards the distance between the molecules as determining the force); a solid mixed in water is denser; a denser solution has more drops; the soap is heavier than the water, and so on. They add the factor of the dropper opening as influencing the size of the drop. The joint report is mostly based on the individual reports, but contains some new information about the forces studied indicated by (+).

Group F: Individual reports

1. "The smaller number of the water drops indicates stronger cohesion forces between the molecules of the water than in the soap solution".

2. "The results show that cohesion forces between the water molecules are stronger than those in the soap solution because the water separated into less drops and went out with more difficulty than soap drops did".

3. "The soap had more drops because it is denser and the molecules are much closer to each other. In the water the molecules are further apart from each other and it is easier to separate them.

4. "The soap solution has smaller drops than water and get out of the dropper faster".

5. "The soap solution had a larger number of drops than water, and it can be concluded from this that the cohesion forces are stronger in water than in soap because of the molecules".

Group F: Joint report

"The cohesion forces in water (the connections between the water molecules) are stronger than those in the soap solution (1,2,5). This is indicated from the fact that the soap broke down to many pieces (drops) while the water broke down to few pieces (1,2,3,4,5). In the water the molecules were stronger (+) and more connected to each other in contrast to the soap (1,2,5). Part of the group members thought that because the water was more diluted (-3) there was a smaller number of drops (like in the case of air that is more diluted than water and contains less molecules). Part thought that there are no relations between the number of drops and the dilution of the water since the influence is from the cohesion forces and not from the dilution of the water".

Analysis of group F reports

Members of group F wrote some correct conclusions, but no one gave a full explanation of how elements relate and influence each other. They tried to integrate a correct part of the response (cohesion is stronger in water) with the prior intuitive notions they possessed (water is more diluted, which is the reason it contains less molecules, which means less drops). The formulation of the answers was very inaccurate (the water molecules are strong - probably meant cohesion is strong; water molecules are connected to each other - probably meant not a chemical bond but the forces acting between these molecules). Such inaccuracy may lead to serious misconceptions that will inhibit further learning.

General remarks on phase 4

The concept of density was conceived differently by different learners. Some viewed it as having more molecules per volume unit (which fits the definition of "diluted" in group A), which the demanded the investment of more energy in pushing the drop out of the dropper. Others used the term to mean more molecules of one kind per volume. Students' understanding of what happened when soap was added to water was related to their understanding of the concept of density. Group A, who started with the data available to them (given and obtained), arrived at the correct conception that, because the adding of the soap resulted in smaller size drops, it meant a weakening of the cohesion and adhesion forces, and thus an enlarging of the distances between the molecules. Thus soap was more diluted because in the same volume there were less molecules, further apart from each other. Other groups did not start with the data available, but rather with intuitive information (treated as a fact) that soap solution is denser. Therefore they conceived the distances between the water molecules as constant, meaning that if some other molecules were added, the latter had to locate themselves between the water molecules without altering these distances which would results in a larger number of molecules per volume, namely the density increased ("solid mixed in water is denser"). While Group A used the data, interpreted it with the forces they previously knew and visualized the situation as dynamic in nature and changing according to the forces acting within it; other groups ignored the forces known, and visualized the situation as static in nature, even when conditions changed.

Usually students did not refer to the gravitation as a "pulling" force in this experiment, but rather to the pushing pressure that the human hand activates by pressing the rubber of the dropper. They believed that gravitation acts equally in all situations, but that the pushing force was changing and thus acted as a factor that influenced the results. Some students mentioned the weight of the liquids in this context.

4. <u>Differentiating between results and explanations</u>.

At the beginning of the learning process, questions regarding the reasons for phenomena was not sufficiently addressed by the students. Conclusions of the less successful students mainly repeated mainly the obtained results of the experiments, with no attempt of explaining the results; for example, "The stem of this specific plant cannot absorb this colored liquid." Or "earth absorbed a quantity of x cc of water, sand of y....". Better students tried to explain: "The stem is covered with a layer that is impermeable to the liquids examined" (regretfully not taking into account the slice at the end of the stem through which anything could enter the stem). When students included factors that might have influenced the results, they never tried to explain the relationship between them: "The height measured for various liquids in the capillaries is different because of the differences in the density of the liquids", or "Different solids absorb different amounts of water due to their different texture".

The above observation raised the need for teaching students to search deeper for the causation of an observed phenomenon, and to try to understand the relations among the factors influencing and determining its results. Mainly, a need was felt to lead students from thinking about every day phenomena at the macrolevel (what is seen is what happens), toward looking for the tacit microlevel explanation. This was done by introducing the physical forces to the student and then demonstrating their action mode in all the examined situations.

5. <u>Explaining a newly defined phenomenon by applying relevant retrieved knowledge according to an explicit identifying cue</u>

Phase 2 presented an example of students' ability to apply knowledge in a new situation that could be identified as suitable for such an application. This identification occurs due to an easy recognition of a clearly observed clue in the phenomenon, which will act as a trigger for drawing out the relevant knowledge from the student's cognitive structure. The better the newly acquired knowledge is organized and categorized in the student's cognitive structure, the better the chances for relevant information to be identified and retrieved for use in a new situation.

In the summarization of phase 1 (after experiencing hands on activities), examples of liquids rising in different types of capillary tubes were explained and discussed (glass tubes, earth texture, and plants' tubes). "Liquids rise" (in spite of gravitation) was the identifying cue common to all cases. In the new situation addressed in phase 2 (the process of chromatography), "liquids rise" was the most obvious phenomenon observed. Using this element as a cue enabled students to draw upon the relevant knowledge (cohesion, adhesion, etc.) while attempting to explain the chromatography.

The simple process of chromatography that students practiced could be broken down into five steps, starting at time "o" when the paper was put into the water: (a) water filled the spaces in the paper up to the water level in the test tube due to a difference in the pressure of the liquid, which is a function of the vertical height, liquid density, and gravitational constant (g); (b) water rose in the paper above the level of the water in the test tube due to the forces of adhesion (acting between the water molecules and the paper molecules) and cohesion (acting between the water molecules themselves) that are larger than the force of gravitation (acting to prevent the rise); (c) the rising water dissolved the ink and carried it upwards due to the forces of adhesion and cohesion (acting between the ink and the water molecules, and between the ink molecules themselves); (d) in the course of this process, the ink, which is made of several types of molecules that differ in weight and color, started separating according to weight and showed strips of colors- the heavier molecules remained behind while the lighter molecules continued to rise with the water; (e) the process ceased when the force of gravitation (increasing with the increase of the water-ink quantity in the paper above water level in the test tube) exceeded the forces causing the rise.

About one-third of the students correctly included steps b, c, and e in their explanations of the phenomenon observed, and stated clearly that the paper could be perceived as being composed of capillary tubes. About an additional third of the students correctly explained the rise of the water, but ignored the gravitation against which these forces acted. Only three of the class students addressed step a, perceiving it as caused by forces different from those acting in the next steps. This was expected because the issue of liquid pressure was not stressed in class. No one in the class correctly explain the idea of the different colors of the ink (d).

Some examples of the students' answers are cited in the following paragraphs.

1. An excellent student: "The water rises in the paper and carries the ink with it. The molecules of the paper pull the molecule of the water upward by adhesion forces. The upper molecules pull the rest of the molecules by cohesion forces. The molecules of the liquid rise in the spaces that exist between the paper molecules, which act as capillary tubes. Reaching the ink

molecules, they combine with them in a chemical reaction and both continue rising upward. The ink color weakens due to its being spread over the paper. The water enters the paper at the first stage due to the difference in liquid pressure in the paper and out".

2. A good student: "The liquid rise in the paper is due to adhesion forces between the liquid and the paper. It pulls more liquid by cohesion forces. The liquid stops rising because the air pressure and the gravitation force prevent its rising, being stronger than the adhesion-cohesion forces due to the weight of the water. The ink also rises with the liquid due to the adhesion forces (and lack of rejection) between these materials".

3. An average student: "The water rises by cohesion (molecules combine with themselves) and adhesion (molecules combine with a solid body), and by absorption. The paper absorbs the water. It includes tiny pores in which the water rises utilizing cohesion and adhesion. The pores are so tiny that it makes it easy for the water to be held in them. The ink becomes lighter in color because the water carries it with it by the same forces. The smaller the pores are, the easier it is for the water to rise because it is easier for the water to enter the pores".

4. A low achiever student: "The paper absorbs the water that slowly covers the it all. The color of the ink is changed due to the fact that it is diluted by the water".

These exemplary answers demonstrate the idea of the "identifying cue". Only the lowest achievers of the class were not able to identify the cue of "rising liquid", and use it for explaining the phenomenon by making the connections to other cases involving rising liquids that were previously studied. They used their intuitive knowledge in a the macrolevel explanation of "absorbing", and were not able to combine it with the microlevel scientific interpretation of the meaning of absorption. Some average students, used the concept of absorption in their answers, but were able to describe the forces causing such absorption. The better the student, the more detailed the explanation, and the more careful and accurate the formulation; each phase of the phenomenon was interpreted separately. But sometimes, a good student also incorrectly used prior knowledge (assuming that a chemical reaction occurred between the water and ink).

The idea of separating the ink constituents according to weight involves a microlevel explanation that could not be identified by the students. Most of them recognized the color spreading upward as the identifying element for liquid rise, and could explain it correctly. Knowing nothing about the ink composition they were not able to interpret the colored lines as different materials. Confusion could also have been a result of the fact that all ink constituents were bluish in color, and therefore were perceived as diluted ink.

As in the other cases, inaccurate description ("molecule combine with themselves") could be the result of either misconception or inferior verbal ability.

6. <u>Explaining a new undefined phenomenon containing a tacit identifying cue</u>

Because most of the students succeeded in explaining the basic principle of chromatography, they were asked to identify any new phenomena in their surroundings that might be explained by the same physical forces. Few students performed the task successfully. In these cases, the identifying cue was clearly visible. For example, a student wrote in the report: "If we hold a sugar cube in a way that its edge will touch the surface of the liquid, the liquid will rise and fill all the tiny spaces between the sugar crystals. The liquid molecules stay together because of the cohesion forces. The sugar cube and the liquid unite by the adhesion force". Another wrote "Inside the lord pen (a pen widely used for writing and coloring) there is an inner sponge wrapped in plastic and an outer sponge around it. This is similar to the capillary tube. The ink is pulled upward in the inner sponge due to the adhesion forces, and passed to the outer sponge in which it flows downwards due to the adhesion forces between the ink and the sponge and the ink and the paper. Gravity helps the ink to flow downwards to the paper".

In other cases students repeated phenomena that were discussed or demonstrated during class hours, or ones very similar to it. For example, a student reported: "Water rises in a straw higher than the level of water around it. This happens because of the adhesion and cohesion forces and in spite of its being contradictory to the different pressures of the liquid columns".

Few were able to generalize, to use cohesion and adhesion in a new context not containing the identifying cue. For example, a student reported: "A drop of water clings to a leaf. The cohesion force holds the water molecules together. The adhesion force holds the water drop on the leaf. The gravitational force pulls the drop downwards, and if this force will be stronger than the adhesion between the water molecule and the leaf the drop will fall. The air presses the drop from above". Although the cue of "liquid rise" is missing here, other recognized details are present, like the water. The next example of student's report has no explicit identified cues. The forces are to be generalized and applied to gas in an entirely new situation: "Most types of gasoline do not burn completely in the engine. This means that not all of the particles are separated. Instead they form small groups of dirt. The particles stay as a group due to the strong cohesion forces between them. These groups, being hot, are lighter and rise and cling by adhesion forces to the exhaust. Other heavier groups sink, due to the gravity, to the bottom of the exhaust and adhere to the wall by adhesion force". Another example: "The atmosphere rotates with earth. The first layer of the atmosphere (the lower layer) is pulled by the gravitational and adhesion forces of earth. The second layer is pulled by earth gravitation as well, but with the adhesion of the first layer. The atmosphere is composed of elements that are located according to their weight at different layers. At the very high layer (the farthest from earth) gravity weakens, the atmosphere is diluted, and therefore cohesion and adhesion are small".

The above two examples were given by very good students. It is obvious that they had well organized macrolevel prior knowledge, to which they applied the microlevel explanation thus making the right connections. It seems that they were able to generalize the forces studied to any phenomena involving molecules in any state. It can not be concluded from the present investigation how this process occurs.

Few other good students correctly generalized their knowledge of the forces beyond the case of rising liquids. They used the forces as identifying cues but not knowing enough physics, they applied them in the wrong situations. For example: "The magnet sticks to the fridge because of adhesion forces". This student assumed strong adhesion forces between various metals. "Electrons move in all directions, but when exposed to a power source they move in one direction only. The electrons reject each other, which means that there are negative cohesion forces between them. Adhesion appears when they are exposed to the power source and move in one direction". From these examples it can be concluded that the limitations and conditions of the forces studied should have been stressed more carefully.

7. Explaining a newly defined phenomenon by generalizing the identifying cue

Students' reports of phase 4 were described earlier while discussing the issue of individual versus group reports, and will not be repeated here accept for some remarks concerning students' ability to explain the experiment. The identifying cue of "rising liquid" (which served as a trigger for retrieving the knowledge of the forces required to explain the phenomenon of chromatography) was not explicit in the present water-soap study. But as indicated by students' responses, encountering more diverse situations enabled them to generalize the identifying cue so that dealing with liquids (not rising) was enough of a clue.

Students had to explain the macrolevel phenomenon of different numbers of drops in two different liquids by using the microlevel knowledge of the tacit forces between and around molecules. In order to be able to apply these forces correctly (which of the forces act, where do they act, how strong are they, what are the differences between the liquids, etc.), students should have started from the results obtained (number of drops per constant volume of liquid). These results may be considered as intermediating agents, enabling the student to arrive at the relevant knowledge while searching through the cognitive structure. Any other attempt to solve the problem would have required stating an assumption, based on prior intuitive knowledge, and most commonly a misconception. The analysis of students' responses yielded that these exact results.

Some students used only part of the data (number of drops only), and therefore were not able to arrive at the correct explanation of the phenomenon observed. Some tried (as in phase 2) to integrate their own conceptions of soap and water with the data and the forces involved. In such cases contradictory sentences was found in the same answer.

CONCLUSIONS

Several steps were employed in teaching students to perform a biology enquiry and to explain macrolevel every day phenomena by using knowledge of microlevel factors acting in the situation. The following factors were found as promoting students' ability to perform the task successfully: (a) training students to formulate ideas accurately; (b) constantly exposing students constantly to both theory and practice (demonstrations and hands-on activities) of a wide variety of enquiries, and demanding written, well organized, and consistent report; (c) training the students to ask "why" and "how", instead of being satisfied with description of phenomena; (d) letting students experience diverse modes of knowledge processing and construction; (e) equipping students with microlevel tools that will enable them to interpret the phenomena encountered; and (f) training students to identify the knowledge that should be retrieved for explanation by moving them through an hierarchical set of new situations, this should start with well defined situations in which the microlevel identifying cue is clearly obvious, move on to well defined cases in which the identifying cue is less and less obvious and more generalized, and finally to situations where the identifying cue is tacit and can be recognized only through intermediating agents.

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