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AUTHOR Fellows, Nancy
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ABSTRACT

To analyze a student's conceptual changes, analyzing transcriptions of writing and verbal statements may not provide enough information. In a study of 25 sixth graders learning about matter and molecules, concept mapping of students' stated ideas was used to analyze the kinds of organizational changes the students made to use new science information. Mapping student statements across time should provide insight into the ways they restructure knowledge. Methodology used and findings are reported for 2 of the 25 students as they studied matter and molecules. Interviews, student writings, transcripts of their remarks, and observations of classroom instruction were used to make the concept maps. Maps were constructed by placing each concept in a circle and connecting the circles as concepts were mentioned. Comparing the maps over time reflected changes in student thinking. With the aid of instruction, students organized their information more usefully and their maps became more organized, with more hierarchical levels. Implications for teaching and learning are discussed. Eight figures of concept maps are included. (Contains 24 references.) (SLD)

Mapping Conceptual Change in Matter and Molecules

Nancy Fellows
Northeastern Illinois University

Paper presented at the Annual Meeting of the
American Educational Research Association
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Mapping Conceptual Change in Matter and Molecules

Carol's writing before instruction:

. . . [a heated ball] stays the same size [because] if it didn't melt, how could it get smaller? It did not get larger, so it would have to stay the same size.

Carol's preclinical interview statements:

. . . I thought it [heated iron ball] would get bigger. . . I don't know why. . . maybe the ball is hollow inside. The steam makes it get bigger. . . steam goes into it.

Carol's writing later during instruction:

. . . the ball's volume will get larger. . . the molecules would only vibrate faster; they also will spread out further apart.

Carol's post clinical interview statement:

The molecules are moving farther apart which was making the ball bigger. . .

As a teacher or researcher trying to make sense of sixth grade Carol's changes in thinking, her writing and verbal statements at various times of instruction are enlightening. Carol has new, more acceptable scientific understanding about thermal expansion during and after instruction. Access to Carol's verbal statements from clinical interview and her written ideas at various times during instruction provided two different and complementary views of Carol's sense-making about thermal expansion. To analyze the changes that Carol made in her thinking, analyzing transcriptions alone of writing and verbal statements may not provide enough information about the kinds of changes Carol accomplished and the ideas she used to make sense of science. In a recent study observing Carol and her 24 classmates while learning about matter and molecules, I used concept mapping of students' stated ideas, like Carol's, to analyze the kinds of organizational changes students made to use new science information. The purpose of this paper is to share a method of analysis for understanding students' conceptual changes across time, and some of the results of that analysis.

Learning in Science and Conceptual Change

The purpose for the concept mapping methodology arose from questions about the processes students undergo to learn science. Research over the past several years has shown that learning new science concepts so they can be used and understood is difficult for many students in science (Anderson & Roth, 1988; Anderson & Smith, 1987; Carey, 1986; Glaser, 1982; Posner, Strike, Hewson & Gertzog, 1982). Often learners begin study of new science concepts with alternative or real-world conceptions about how the world works based on their previous experience. In order to make sense of the new information, learners have to accommodate their thinking and either abandon old schema or revise their schema in order to understand the new information (Piaget, 1950; Rumelhart & Norman, 1981). When students restructure within a domain, such as the matter and molecules subject of this paper, they add new concepts and theories, and develop more sophisticated logical capabilities within the domain---they restructure their knowledge by abandoning or modifying their existing real-world schema to accommodate and make sense of new ideas (Carey, 1985). Mapping students written and verbal statements across time as they were learning might provide insight into the way students restructured their knowledge or modified their existing schema organization.

In addition, learners have difficulty making conceptual changes in thinking and often do not completely shift their existing knowledge to fit with new information. Learners commonly change pieces of new information so it fits their existing knowledge; or they will learn new scientific terminology and algorithms yet continue to use prior real-world knowledge to solve real-world problems (Carey, 1986; Driver & Easley, 1978; Roth, Smith & Anderson, 1983). Researchers have proposed that conceptual changes are developmental and take a long time even under conditions of good instruction (Nussbaum & Novick, 1982).

Investigating thinking. Realizing how difficult changing conceptions about science can be, researchers interested in how individuals change their conceptions have documented students' thinking by (1) investigating students' misconceptions (Viennot, 1979), (2) analyzing students' perceived similarities among elements (Chi, Glaser & Rees, 1982), (3) analyzing students' problem-solving processes (Larkin, McDermott, Simon & Simon, 1980), and (4) analyzing students' knowledge using "concept mapping" as a representation of students' concepts in graphic form (Carey, 1986; Chi, Glaser & Rees, 1982; Novak & Musonda, 1991). The usefulness of concept mapping for observing thinking changes of the same student over a twelve year time span was demonstrated by the work of Novak and Musonda. Observing concept maps derived from students' statements over time in this study provided insight into where the difficulties might lie in matter and molecules subject matter, and provided more specific and useful information for enhancing instruction than analyzing students' writing and verbal statements alone.

In this paper I report methodology and resulting findings for two students of the 25 studied as they attempted to understand matter and molecules (Fellows, in press, 1991). Concept maps served as graphical pictures of the concepts students identified in their written and verbal statements throughout a twelve week lesson unit. The maps were studied for changes over time in organization, drops and additions of concepts, and addition of useful scientific explanations.

Sources of Data for the Maps

Clinical Interview

Clinical interviews have been used to assess students' conceptions for many years (Chi, Glaser & Rees, 1982; Novak & Musonda, 1991; Nussbaum & Novak, 1976; Piaget, 1950; Posner & Gertzog, 1982) A clinical interview is designed to gather information about the nature and extent of an individual's knowledge, particularly concepts and their relationships within a particular domain. Sometimes clinical interview data has been represented in concept map format as a partial representation of the individual's cognitive structure (Chi, Glaser & Rees, 1982; Novak & Musonda, 1991; Posner & Gertzog, 1982). In some cases interviewers have first mapped the concepts for conceptual content of the lessons, then used the maps as guides for conducting the interview. Even though clinical interviews are widely used, there is little agreement on how such interviews ought to be systematically analyzed. Mapping the conceptions students identified during their interviews seemed relevant in this study to observing changes in thinking over time. In a later section I describe how the mapping methodology was designed and implemented to partially represent students' conceptions and their organization over time.

Student Writing

Because writing data for 25 students was easier and less time consuming to obtain than interview transcripts, student writing was used for the greater part of the data about student thinking about matter and molecules. Over the past decade researchers have shown that student writing provided a methodology sensitive to distinguishing changes in students' thinking (Ammon & Ammon, 1987; Kleinsasser, Paradis & Stewart, 1992; Tierney, Soter, O'Flahavan, & McGinley, 1989). Student writing provided a vehicle for teachers to follow students' changes in thinking as they moved from topic to topic and expressed their understanding of concepts (Staton, Shuy, Peyton, & Reed, 1988). Student writing, when it was encoded into concept maps as described in this paper, provided a useful way to observe how thinking might have changed across time and learning.

Classroom Instruction

As a control for comparison, the classroom instructional material was mapped for concepts and organization as it was presented to the students. This data served to support and help explain some of the changes seen in students' concept maps.

Transcripts of Target Student Verbal Classroom Remarks

All of the verbal remarks made by six target students during whole-class instruction and during small group activities was transcribed chronologically according to date and classroom time. These verbal remarks were compared with student maps taken from similar time periods to support the data from student writing. The transcripts were used to aid understanding of concepts students might have considered as they constructed their written explanations.

Methods

Subjects

Twenty-five students in an urban middle school sixth grade classroom were selected from among six classrooms currently engaged in a larger three-year study to test the effectiveness of a conceptual change learning unit using teaching for self-regulation and small group problem solving (Anderson & Palincsar, 1990). This classroom was selected for heterogeneity of achievement and ethnicity among the students, and a teacher who instructed using conceptual change teaching strategies (Anderson & Roth, 1988; Anderson & Smith, 1987), such as eliciting students' alternative real-world conceptions about matter and molecules and making students aware of the conflicts between their real-world conceptions and accepted scientific explanations.

Subject Matter and Instructional Strategies

The subject matter was the nature of matter and physical change covered in a Matter and Molecules Unit designed by Anderson, Eichinger, Berkheimer, & Blakeslee, (1990) and Anderson & Palincsar, (1990). The unit had been developed over a 2 year period and had proven more effective than an equivalent commercial unit in promoting conceptual integration and ability to use scientific knowledge. The Matter and Molecules Unit was presented in 5 lesson clusters consisting of (1) pure substances and mixtures, (2) understanding powers of ten and introduction to molecules, (3) molecular behavior in changes of state, (4) dissolving, and (5) thermal expansion.

Data

Each student was given a paper and pencil pretest prior to beginning the learning unit and the same test as a posttest. Students' answers to multiple choice questions and their corresponding written explanations from the pretest and posttest were included as part of the writing data. Six target students were clinically interviewed about the matter and molecules subject matter before and after instruction. Data collected was all student writing about the subject in activity booklets, videotapes of classroom lessons and small group discussions, and periodic interviews during instruction about students' facility with writing tasks. Students' written remarks were anonymously transcribed into files according to topic. For instance, student #1's statements about molecular behavior went into her "molecules" file, and statements about molecules in dissolving went into her "dissolving" file. All transcribed statements were used to construct concept maps for students' statements.

Concept maps

Concept maps were used to transform students' writing transcripts into representations of their knowledge structures. The concept mapping procedures developed and reported in this paper were similar to those constructed by Chi, Glaser and Rees (1982). Chi and others demonstrated a method of graphing potential schema by constructing concept maps based on what individuals mentioned contiguously in their oral statements. They determined the knowledge organization of experts' and novices' schemas by using semantic node-link networks (concept maps) of key terms mentioned by the subjects in their elaboration protocols. Concept maps were constructed in this study by placing each concept the student mentioned within in a circle, then connecting that circle to the next concept the student mentioned. Concept maps were studied for differences in numbers and types of concepts, the connections between concepts, and whether the student appeared to have organized his or her schema around a new principle over time that came closer to accepted scientific explanations of the phenomena.

Concept maps representing students' written ideas were similar to the example that follows. Ken's written statement during the pretest about states of matter is as follows: ***[water weighs less than ice] because ice is solid so it makes more weight.*** The procedure for mapping Ken's statement was to start with the concept he mentioned first. The question Ken answered was multiple choice as to which weighs more, ice or water. "Water" and "weighs less" were Ken's response, so each was circled and connected. "Ice" was next in the statement, so "ice" was circled and connected to his previous statement, "weighs less". The next concept Ken mentioned, "solid" referred to "ice" so "solid" was drawn and a connection made to "ice". "More weight" is the last concept mentioned, and it was connected to the previous concept, and to "ice" because by "it" we assumed Ken referred to "ice". Figure 1 shows the concept map for Ken's statement above. The maps were constructed to correspond as closely as possible to students statements so any hierarchies present would arise as a result of students' statements rather than being imposed by the analysis.

Reliability. Three science education graduate students were instructed in the techniques of concept mapping. Their resulting concept maps for the same written samples were similar in structure, with differences only in the positioning of words in space, but not in substance. Novak and Musonda (1991) showed that concept maps of students cognitive structure remained stable over a 12-year span and interviews by different researchers, indicating that mapping clinical interviews is a reliable and valid representational tool for an individual's cognitive structure, and may "measure aptitudes not commonly assessed by typical objective tests" (p. 34).

Concept map changes over time. By qualitatively comparing students' concept maps across time, I analyzed (1) concept changes among maps about similar content, (2) changes in map structure, (3) persisting alternative conceptions, and (4) how close each student came to using accepted scientific explanations of matter and molecules within their map. My assumption was that more concepts, well-organized to usefully explain phenomena, and more levels in a students' concept map might signal greater differentiation and therefore, better understanding of concept meanings.

The criteria for determining concept map changes were as follows:

(1) Are there new structures in the map containing different individual concepts? What are the new concepts?

(2) Does the structure differ and/or the domain the map explains differ in later map? What new domains are explained?

(3) Does map appear to be more organized (i.e. does it contain more hierarchical organization coinciding more closely with scientific explanations)? How many more levels appear now?

(4) Are there any persisting alternative real-world conceptions? What are they?

The maps were not scored quantitatively, because I was interested in the kinds of changes that students made and when, and not how many changes were made during the course of instruction.

Reliability. To establish the reliability of the interpretations of the maps, the criteria for assessing students' restructuring and changes in concepts over time were carefully defined and applied consistently across all student samples. Three trained graduate students' analyses of the same maps were at least 80% similar for interpreting concept maps for all types of changes, map differences in concepts within map, differences in domain or structure, and differences in hierarchical organization.

Data Comparisons for Thinking Changes

Once student maps had been analyzed and I had data on the changes students made during their individually written instructional tasks, I looked more closely at student activities and verbal statements during activities to determine possible relationships between the instructional activities, and group collaboration activities, and how these manifested in students' writing. For the six target students, I compared the concept maps with transcripts of videotaped student verbal remarks during class discussions and small group collaborations, and written products from group collaborative explanations and the comments students made as they worked on collaborative writing. The comparisons were made in chronological order, noting the ideas that students identified in their individual writing before instruction and group collaboration, during instruction, during group collaboration, and during later individual writing. These events continued in the same order throughout the lesson activities: There were student writing samples of their ideas before instruction in each of the 5 lesson clusters, writing accomplished during whole class instruction, individual writing when planning ideas for group collaboration, writing during and resulting from group collaboration, and later individual writing on similar topics. The transcripts were analyzed qualitatively using the maps to check for consistent changes in concepts and explanations students identified over time.

Results

Changes Indicated by Concept Maps

Students' concept maps changed over time in the following ways: For all 25 students, maps became more elaborate with addition of new concepts such as "molecules", "matter", and concepts related to movement and arrangement of molecules, dissolving and expansion. For each student the concepts were constructed into their schema in different ways to explain phenomena related to instruction. Often the concepts and explanations added were verbatim wordings from classroom instruction, such as "molecules don't change, only their arrangement and movement changes". Students showed in their maps that they had added new concepts to their vocabulary. In some cases, the students made the concepts more useful to their explanations. Jose's map changes provide an example:

Are there new structures in Jose's maps, different concepts? Figure 2 shows the map of Jose's writing about molecules before instruction. A later map taken from Jose's writing during instruction (Figure 3) shows that he added concepts of molecular size, and modified his real-world conception that molecules are not only found in air, but are found all around us.

Does the structure differ or explain a different domain? Jose's map following instruction (Figure 4) at the posttest showed that he retained his ideas of the smallness of molecules, although he had forgotten just how small molecules are, and he added new structures that molecules "build things". Jose had added a new domain to his schema because he wrote that molecules can be found in other things than just air.

Does map appear to be more organized, more hierarchical around more accepted scientific explanations? Jose's clinical interview map following instruction (Figure 5) showed his conceptions about the patterns and movement of molecules in different substances, more closely resembling the map of the instructional content and more useful scientific knowledge, and showing more levels in Jose's hierarchy of understanding for molecules. Jose's map from his writing about thermal expansion supported our contention that Jose understood thermal expansion at a macroscopic level---he wrote that a balloon placed on a cold bottle would expand when the bottle was heated by our hands because the air in the bottle expanded to make the balloon get bigger. The concept maps showed us that Jose explained his macroscopic understanding in his written posttest, and it was more organized and useful than his explanation before instruction; he removed water from his schema, and added the concept of heat from the hands to make a more useful scientific explanation after instruction.

Are there any persisting alternative real-world conceptions? Jose was able to explain microscopic understanding better orally at the post clinical interview than he was in writing during the posttest. This could have been because he did not understand that he was to talk about molecules during the posttest (although he was asked to explain in terms of molecules, he may have missed that). Or Jose may not be able to explain his ideas about thermal expansion in writing yet as easily as he could orally explain his ideas. He retained some alternative conceptions in his written concept map because he did not explain by using molecular explanations. He showed some alternative conceptions during the post clinical interview when he said "more molecules go to the top" in his explanation about thermal expansion of air in a heated bottle.

Thinking Changes During Instruction

Perhaps the best evidence for thinking changes students demonstrated in their writing was found during the dissolving lesson cluster, because students performed many different kinds of writing during the lesson. Carol's maps and classroom statements serve as an example: Carol's before instruction map for dissolving is shown in Figure 6. After learning about the motion and arrangement of molecules in different states in an earlier lesson cluster, Carol's map from her individual writing to plan getting sugar out of a tea bag (beginning of dissolving lesson, Figure 7) showed her trying out changes of state conceptions as part of her dissolving schema, sugar "changing from solid to liquid" and molecules in sugar "moving farther apart". When her group collaborated on written plans, Carol added little to her writing. Later after more instruction in scientific explanations for dissolving, Carol added molecular movement "out of a rigid pattern" in sugar. She added to her explanation the resulting action of dissolving in hot and cold water, because molecules either "vibrate much faster" (hot) or "don't vibrate as much (cold). After group collaboration, Carol added "ice" to slow molecules even further for very slow dissolving and molecules "move farther apart" in hot water. In later individual explanations, Carol used similar concepts but added "water molecules hitting against sugar" during dissolving, and "mixing". These were concepts the teacher emphasized during instruction in her scientific explanation for sugar dissolving in water. Later in another writing, Carol continued to use water molecules hitting sugar, slower action in cold water and faster in hot as part of her explanation. By the end of instruction, the concepts that Carol used to form her schema are shown in Figure 8. Her post clinical interview concept map was similar in structure to her map from posttest writing.

From the analysis of students' map changes over time, it seemed that, like Carol, students "tried out" ideas based on their prior knowledge to make a useful explanation, as Carol did with her attempt to use knowledge about molecular movement in changes of state to explain dissolving. When students were unable to use new concepts from the instruction, they often relied on their previously understood real-world ideas for explanations. Group collaboration of ideas helped students try out new ideas in their explanations, sometimes in useful ways. Students seemed to need useful experiences with ideas before they made new concepts a consistent part of their schema. When students did not make useful sense of a new concept, it seemed to drop out of their map at a later time. For instance, in Carol's case, molecules "vibrating" was replaced by "hitting" in later map, the latter likely being more useful to Carol's explanations, and perhaps more like what Carol had observed macroscopically. Carol, like other students, seemed to focus on one or two salient aspects of an observable process or an explanation and continue to use that explanation. The concepts that students retained in their schema seemed to be those they either had used most that seemed for one reason or another to make sense to them, and those that seemed to them to "fit" what they had experienced visually in class. Students had difficulty constructing schema for concepts they had not made useful. One example was students' inability to explain the difference between pure substances and mixtures. Evidenced in the number of writing samples obtained during part of the instruction in pure, mixtures, matter and non-matter, many students could recite that a pure substance had only one kind of molecule but they had difficulty relating that conception to real-world substances and the relationship of substances to non-matter. They had not made the concepts useful in practice with explanations either individually during instruction or in group collaboration. Instruction had provided students with a definition or algorithm, but had not provided them with explanations as they had been provided in other instruction, such as dissolving and thermal expansion lessons.

Summary

Concept mapping of students' written and oral remarks before, during and after instruction often showed changes in concepts, organization and useful explanation. The two students described here illustrate the kinds of cognitive change I observed over the course of the matter and molecules lesson unit. The analysis represents the way concept maps were used to describe and represent students' conceptual changes. Students added new concepts and new structures to their schema to attempt to make the concepts fit their structure, to make the concepts useful. Students may have tried to make concepts useful because the teacher and the instruction coaxed students to provide explanations in several of the lesson clusters. In attempting to come up with an explanation, students tried out definitions and concepts they had experienced during instruction until they found a useful fit. Even when they were incorrect, students attempted to make concepts a useful part of their schema. By attempting to make new concepts useful, students often added new structures or new domains to their explanations. Students explanations across time seemed to focus on one or two salient aspects of a phenomenon. With the aid of instruction, especially if instruction modeled useful scientific explanations, students were able to organize their schema around more useful explanations than they were able to construct on their own or during group collaboration. With more useful explanations from instruction, and practice writing and speaking about their explanations, students' maps became more organized with more hierarchical levels. Many times students retained some alternative real-world conceptions within higher-order organized schema.

Implications for Teaching and Further Research

This study supports and contributes to the conceptual change literature by demonstrating that concept maps are useful for studying individual's conceptual understanding and schema changes. The results showed that students reveal what they understand when they write about their explanations. Providing students with useful explanations to fit observable phenomena seemed to help students construct their own useful and more scientific understandings of matter and molecules. In this study, students seemed unable to come up with useful explanations about phenomena on their own, even though they knew definitions of concepts. It seemed likely that the opportunities students had to collaborate with others about problems and explanations as they experimented with using their new language about matter and molecules also helped them to make sense of the information as was evidenced by students in many cases using phrases the heard other students say to construct their own explanations. When an explanation seemed to be useful to students, and when it seemed to match their observations, they were more likely to retain that explanation. And then students seemed to focus on similar one or two salient points in their explanations again and again. Having students write and rewrite explanations of phenomena using scientific vocabulary may also have been helpful for making sense, because the explanations that students retained were those they had more practice writing during instruction.

The implications for teaching from this study are threefold: (1) Provide students (or coach them) with useful scientific explanations for phenomena they observe, (2) provide students with practice writing scientific explanations, and (3) provide opportunities for students to collaborate with peers as they construct scientific explanations.

Interesting further research might include student-constructed concept maps at various points during instruction to support their written and verbal explanations. Student generated maps and/or maps constructed with peers might also serve to trigger new understandings of relationships in their explanations.

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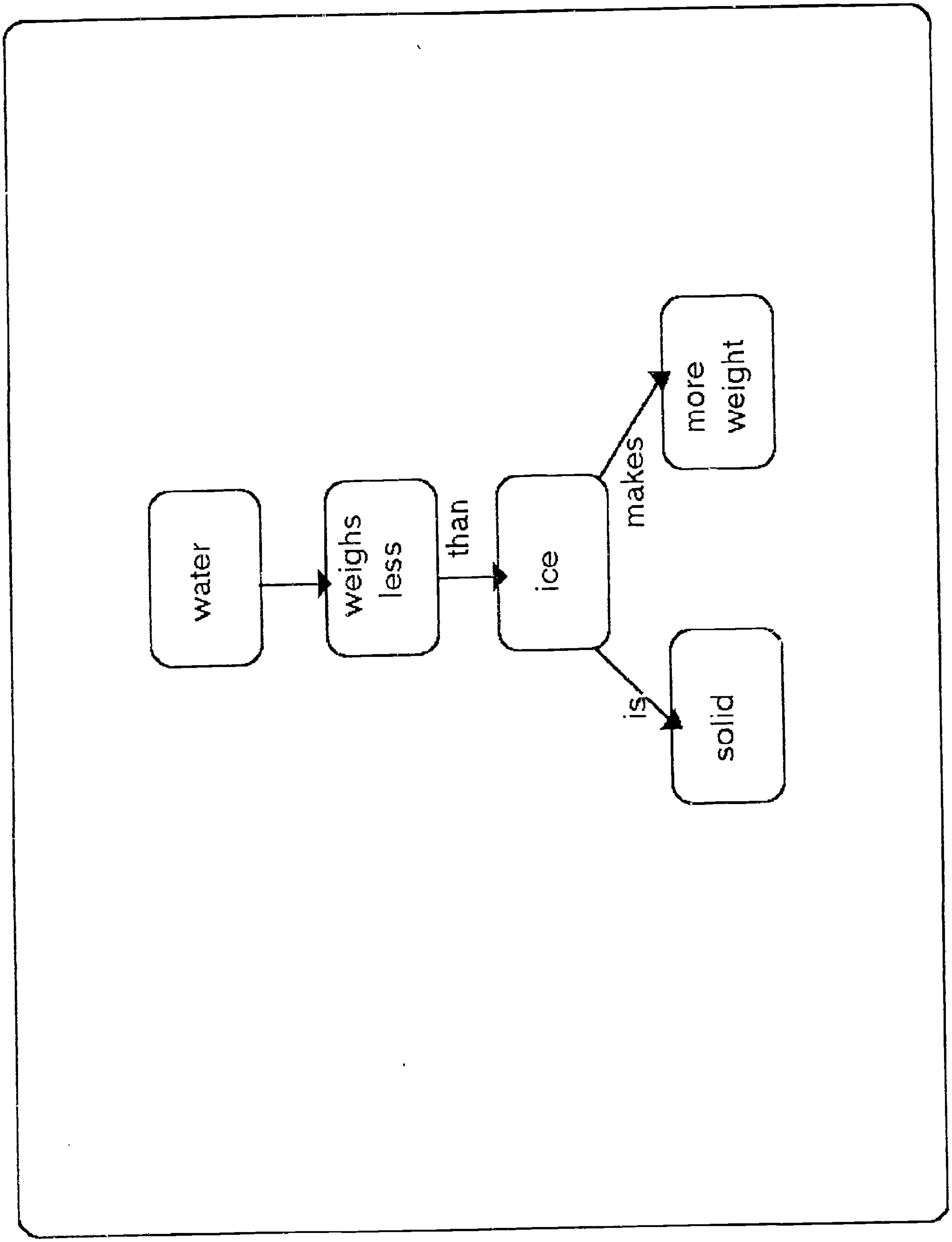

Figure 1

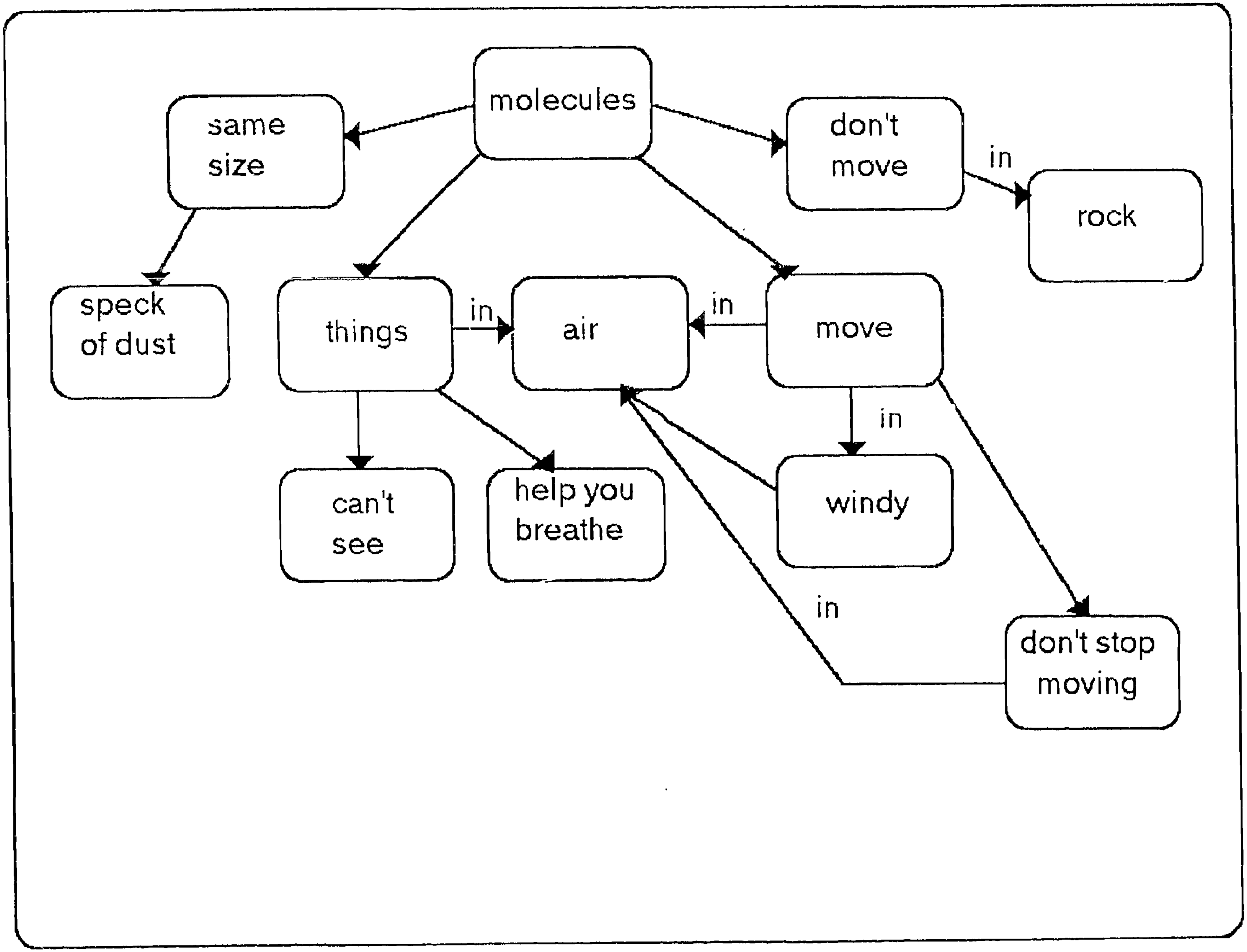
molecules
same size
speck of dust
things
in
air
in
move
don't move
in
rock
can't see
help you breathe
windy
in
in
don't stop moving

Figure 2

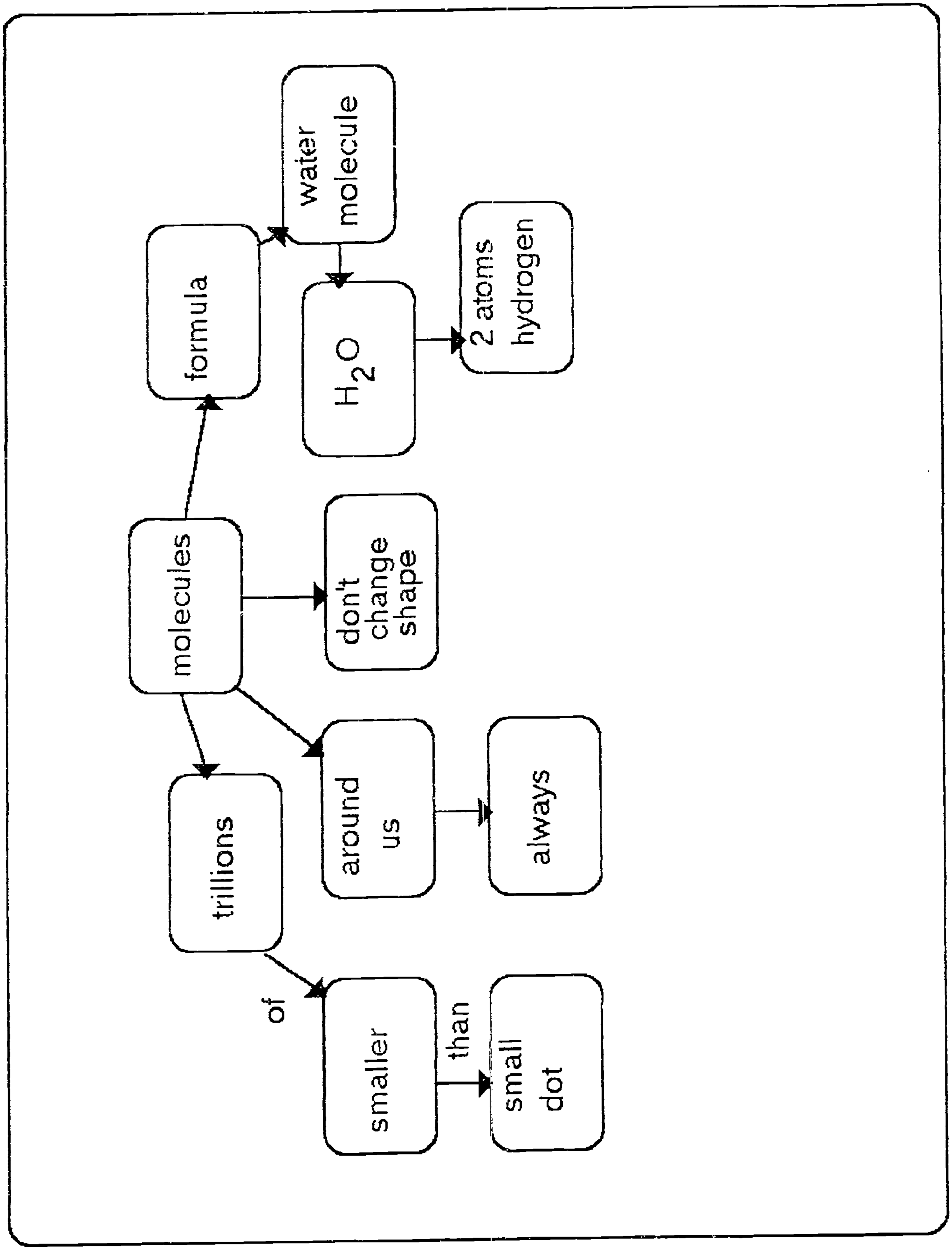
molecules
formula
water molecule
H_2O
2 atoms hydrogen
don't change shape
trillions
around us
always
of
smaller
than
small dot

Figure 3

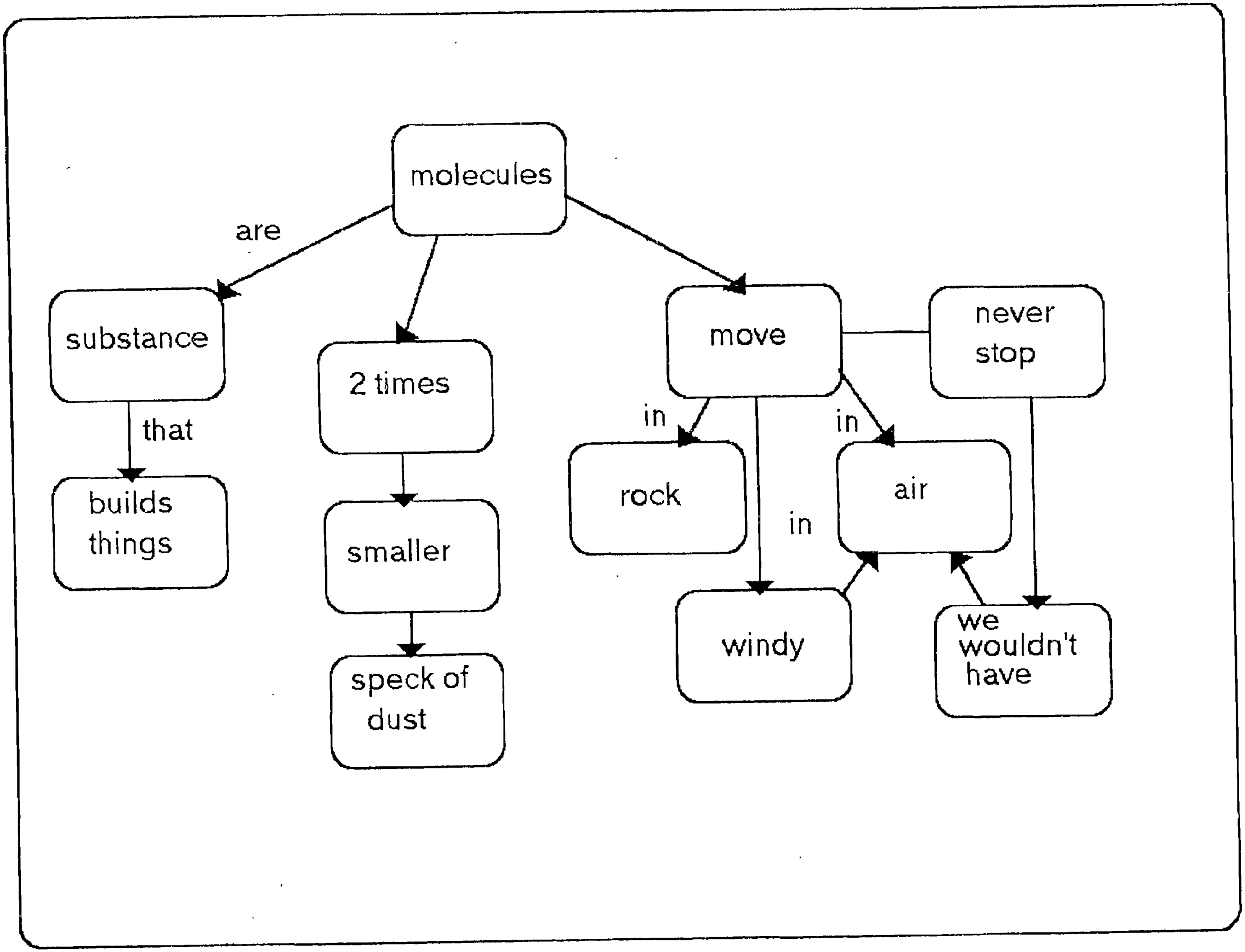
molecules
are
substance
that
builds things
2 times
smaller
speck of dust
move
never stop
in
rock
in
windy
in
air
we wouldn't have

Figure 4

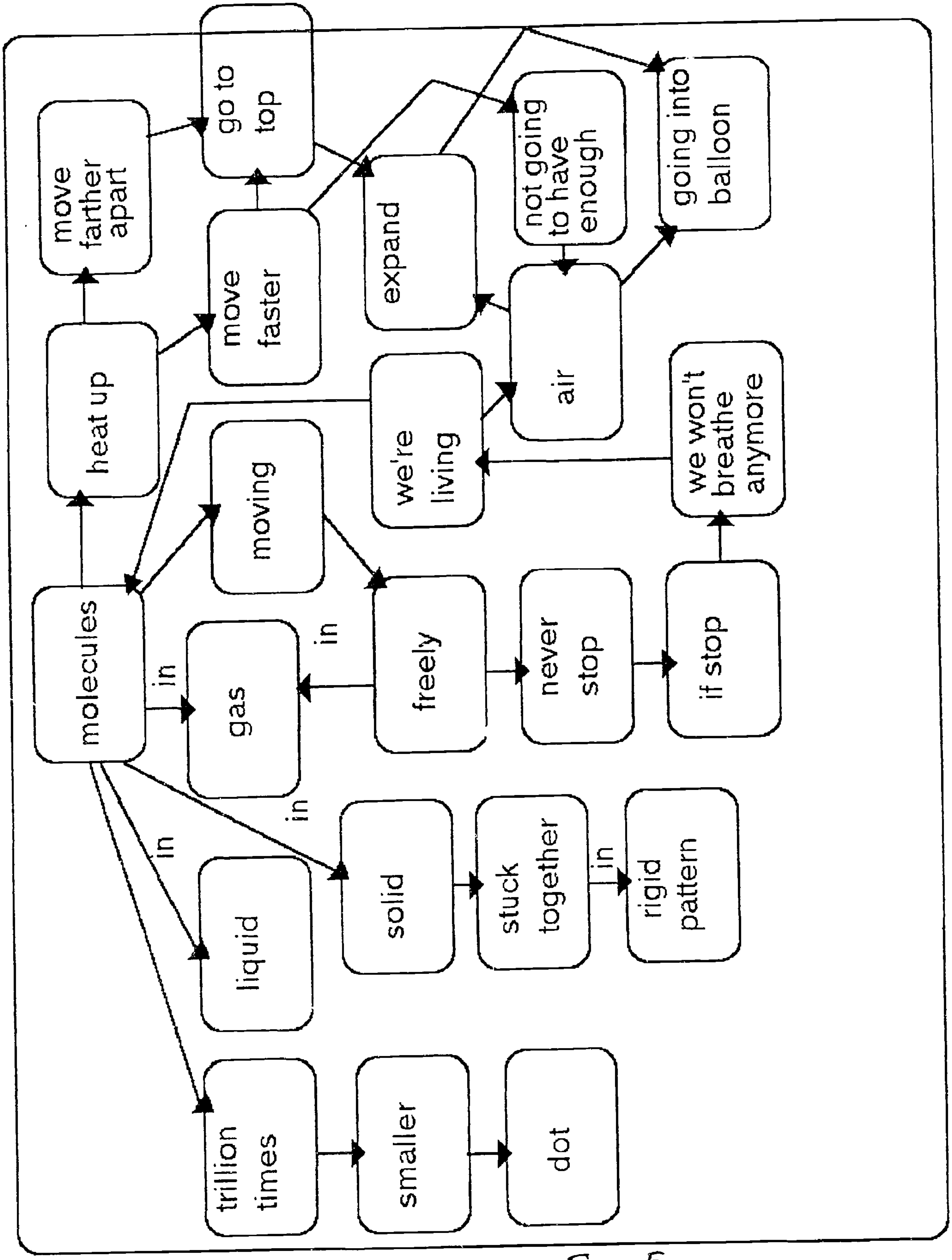
molecules
in
in
in
in
gas
liquid
solid
stuck together
in
rigid pattern
trillion times
smaller
dot
heat up
move farther apart
go to top
move faster
expand
moving
freely
in
never stop
if stop
we won't breathe anymore
we're living
air
not going to have enough
going into balloon

Figure 5

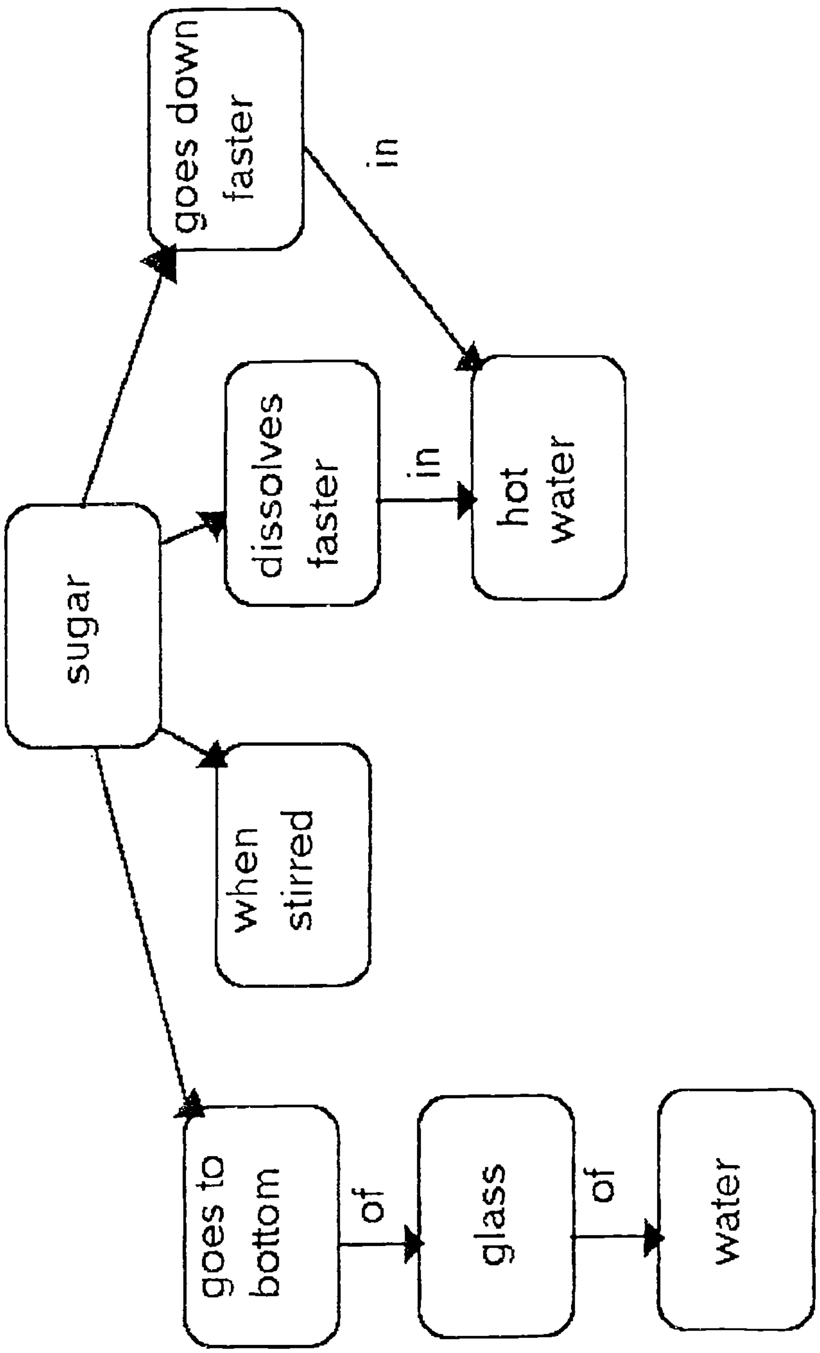
sugar
goes down faster
in
hot water
dissolves faster
in
when stirred
goes to bottom
of
glass
of
water

Figure 6

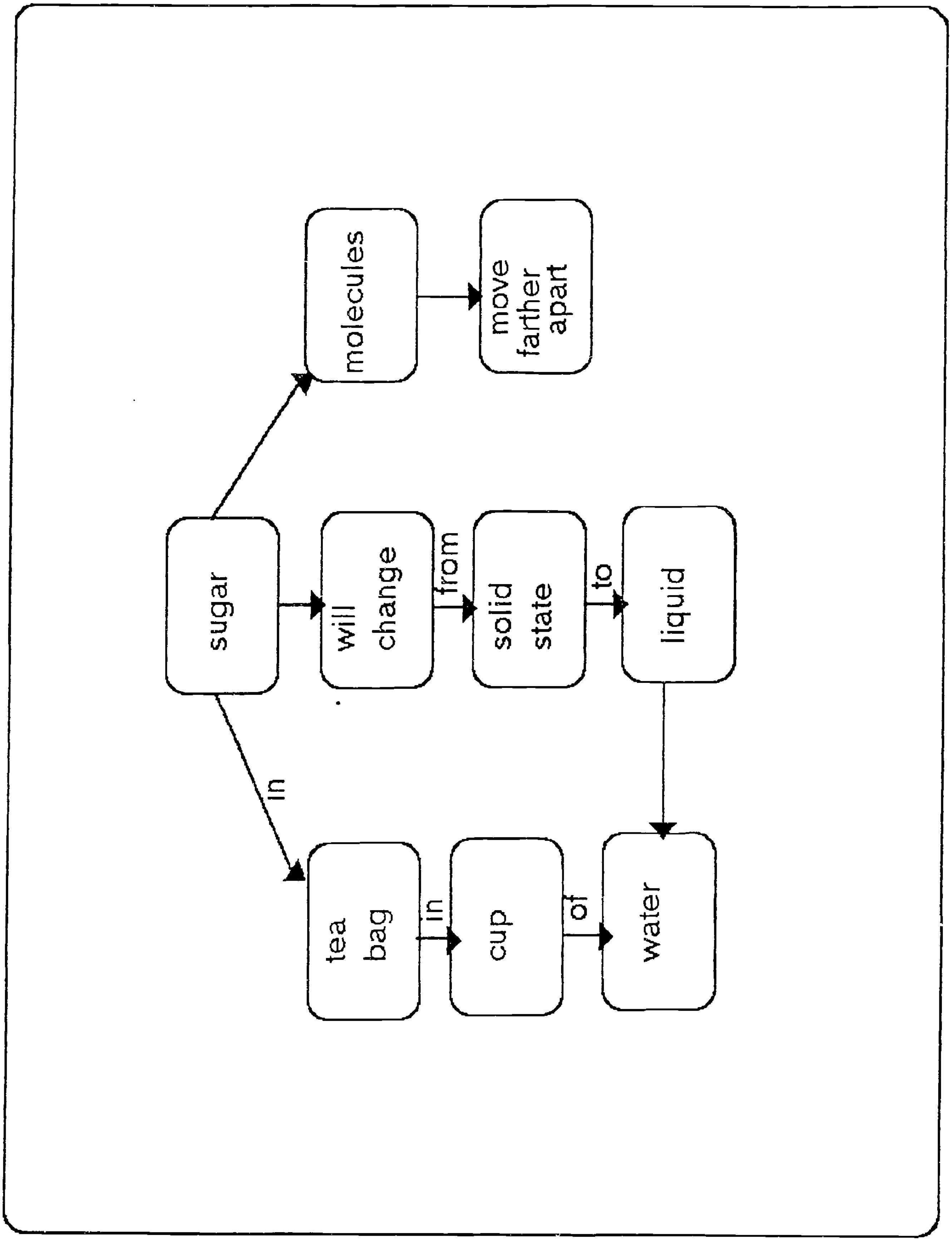
sugar
will change
from
solid state
to
liquid
in
tea bag
in
cup
of
water
molecules
move farther apart

Figure 7

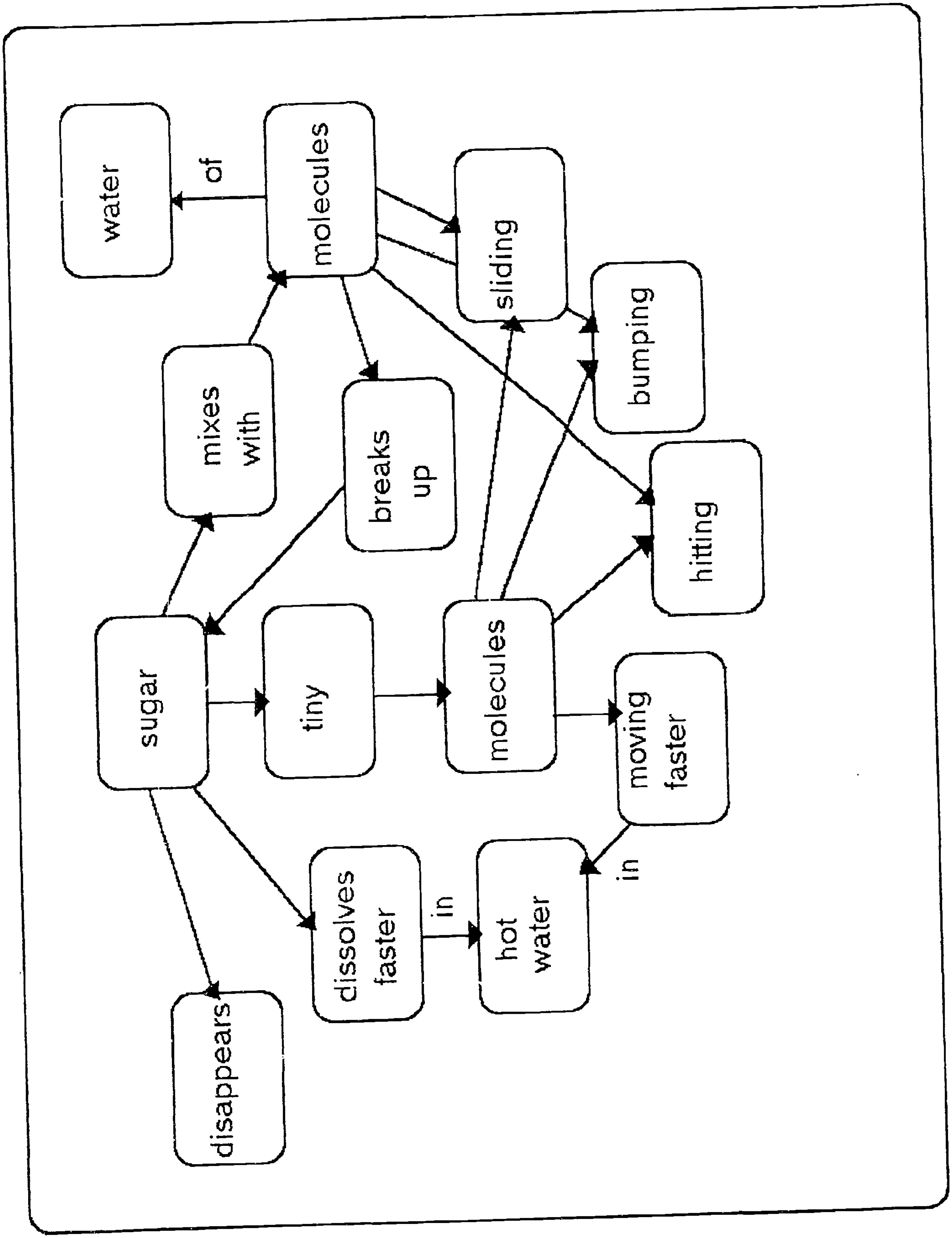
water
of
molecules
sliding
bumping
mixes with
breaks up
hitting
sugar
tiny
molecules
moving faster
in
hot water
in
dissolves faster
disappears

Figure 8