Students' Description of an Atom:
A Phenomenographic Analysis

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Abstract

This study investigates the students' ideas about an atom by asking them to describe an atom on a paper and pencil questionnaire. Students' understanding of the structure of an atom, its constituents and their approximate locations, the size of an atom, and energy released by an atom are investigated. Analysis of responses was based on the phenomenographic method. The study does not attempt to develop a catalog of students' "misconceptions" of atoms. It explores how students describe atoms when they are presented with an open-ended question. We can then learn what ideas are foremost in students' thoughts when they think of atoms.

Introduction

Research on students' conceptual understanding of physics over the past decade has shown that many students in high school and introductory college physics courses are not developing a satisfactory conceptual understanding of physics (Clement, 1982; McDermott, 1984; McDermott, 1991; Novak 1987; Heuvelen, 1991; Fischler & Lichtfeldt, 1991; Sere, 1991). Many of these studies have revealed the difficulties students have in making connections between various representations, basic concepts and principles, and real world phenomena (McDermott, Rosenquist, and Zee, 1987; Goldberg and Bendall, 1992). Many decisions students make about the behavior of physical systems seem to be driven by prior knowledge and beliefs. Osborne and Freyberg (1985) have revealed that the knowledge claims employed by learners are not often well grounded by what they call "sound rules" or relevant associations of concepts. Research in students' misconceptions has found that students frequently have knowledge frameworks that, when taken together, are inconsistent within themselves. This conclusion implies that students' knowledge often consists of separate facts, formulas, and equations poorly organized for retention and use (Heuvelen, 1991; Mestre, 1991). The common factor in all these studies is the identification of student prior knowledge for a better teaching strategy.

In contrast to other areas of physics, research studies on students' conceptions in Twentieth Century physics are limited (Bethge and Niedderer, 1996). Quantum physics is the least attractive area for the researchers because the target audience is much smaller than the other areas of physics. Further, instruction about quantum physics has not generally been available at the introductory level. However, students need to learn more about contemporary developments in physics to understand modern technology. Thus, a better understanding of student views of modern physics is needed. One aspect is student knowledge of atoms.

Students' Views of Atoms and Models

A study by Sequeira and Leite (1990) revealed that students showed a reasonable knowledge about the size and the structure of the atom. The same study showed that 29% of the eighth graders, 35% of adult students and 10% ninth graders did not respond when asked questions about the atom. In contrast Sequeira and Leite, Cros and Maurin (1986), in a study involving first-year university students, reported that the constituents of the atom were “either totally unknown or poorly perceived.”

Bethge & Niedderer (1996) asked German secondary students to draw an atom. They found that approximately 25% of the students' drawings included conceptions close to those of quantum physics, another 25% used conceptions between quantum and classical physics such as “smeared orbits”, and 50% drew the atom in terms of classical physics. One class of students maintained these descriptions even after completing a teaching unit that used quantum mechanical approach in an advanced secondary school physics course.

In another study of German secondary students’ models of an atom, Fischler & Lichtfeldt (1992) taught a unit of 32 lessons concerning quantum physics to a test group of secondary students. In their approach, they did not address the phenomena of quantum physics by referring to the conceptions of classical physics. They found that 68% of the students in the test group oriented themselves toward the conception of localization energy. However, the control group students persisted in the conception of circle and shell.

These studies showed that the majority of the students do not hold the same idea of an atom as physicists. The first studies revealed that over 60% of students did not have an acceptable, if any, description about the size and structure of the atom. Later studies, which concentrated on the atomic models, showed that students still retain classical or semi-classical models of the atom even after the instruction that concentrated on the quantum physics descriptions of an atom.

Albanese and Vicentini (1995) point out that in teaching about atoms the focus is not on the existence of atoms, but on convincing students of the validity of an atomic model in order to explain the macroscopic properties of matter. Therefore, a first issue in this transmission of knowledge may be identified as the epistemological problem of the role of models in scientific understanding. Albanese and Vicentini concluded that “students seem to consider atoms not as the elements of a model which tries to explain macroscopic properties as emergent properties of the collection of the elements (which by themselves do not posses them) but as the smallest part in which a microscopic object may be subdivided while retaining its characteristics.”

On the other hand, Jammer (1965, cited in Bethge and Niedderer, 1996) argued that in physics the concept of a model has evolved through a change from a pictorial representation (“image”) to a “structural similarity with respect to relations”. Bethge and Niedderer (1996) conclude that students consider models acceptable when models seem to be images of reality.

Previous studies reveal a broad range of topics that are directly or indirectly related to the present study of documenting and examining the students’ perception of an atom. Even though some of them revealed some information about students’ perceptions of the size of the atom, none of them revealed any information about students’ perceptions of “small” or more specifically what “small” really means. Also, these studies lacked systematic investigation concerning how students relate an atom to matter. The studies by Niedderer, et al. and Fischler, et al. did not explore students’ conceptions of the structure of the atom even though they studied students’ atomic models. The present study investigates the whole picture of the atom including size and structure of an atom, students’ atomic models and how students relate matter at the atomic level with energy.

Purpose of This Study

This study investigates the students’ ideas about an atom by asking individuals, to describe an atom on a paper and pencil questionnaire. In this questionnaire we probed students’ understanding of the structure of an atom, its constituents and their approximate locations, the size of an atom, and any energy released by an atom. The study categorizes the students’ descriptions of an atom by looking for structurally significant differences that clarify how students describe the atom. Analysis of responses was based on the phenomenographic method developed by Marton (1986).

In this study we do not attempt to create a catalog of students' "misconceptions" of atoms. Instead, we are interested in learning how students describe atoms when they are presented with an open-ended question. We can then learn what ideas are foremost in students' thoughts when they think of atoms. Thus, this study can be the basis for development of instructional materials or studying the process by which students come to understand abstract models in physics.

Phenomenography as a Research Method

Phenomenography is a “research method for mapping the qualitatively different ways in which people experience, conceptualize, perceive, and understand various aspects of, and phenomena in, the world around them." (Marton, 1986) The point of departure in phenomenography is always relational. Phenomenographers deal with individuals, some specific aspect of the world, and the relation by which they try to describe that aspect of the world as it appears to them. Thus, they adopt an experiential, or what phenomenographers call a "second-order," perspective. (Marton, 1981)

Phenomenographic studies have repeatedly found that each phenomenon, concept or principle can be understood in a limited number of qualitatively different ways (Marton, 1986; Browden et al., 1992; Prosser, 1994). The present study assumes that a limited number of conceptions of the atoms and principles related to it can be found.

Phenomenographers categorize their subjects' descriptions, and these categorizations constitute the main outcome of the research. Phenomenographers look for the most essential and distinctive structural aspects of the relation between the individual and the phenomenon (Marton, 1986). Above all, each category is a potential part of a larger structure in which various categories of descriptions exists. A goal of phenomenography is to discover a structural framework that is useful in understanding students' knowledge.

The categories are directly drawn from the students' responses to open-ended response surveys (Prosser and Walker, 1995) or from the students' interviews (Marton, 1986; Browden et al., 1992); no attempt is made to fit the data into predetermined categories. The categories are based on the most distinctive characteristics that differentiate one conception from another and are presented in increasing levels of understanding (Browden et al., 1992). Thus, a hierarchy of students' ideas is a result of the phenomenographical method.

The "phenomenographer must discover and classify previously unspecified ways in which people think about certain aspects of reality." (Marton, 1986) Thus, placing responses in categories and organized systems of categories is the most important outcome of phenomenographic research (Marton, 1986 and Browden et al., 1992). The categorization of descriptions is not merely sorting data, but is looking for the most distinctive characteristics that appear in those data. Thus, one is looking for structurally significant differences that clarify, in our case, how students describe the atom.

General Description of the Study

A questionnaire was constructed in two major steps followed by a modification. In the fall semester of 1995, two questions were asked as part of an extra credit activity in a conceptual physics course (Zollman, 1990). These questions asked students to describe the atom and where they had learned about it.

Based on those responses we constructed a more specific set of questions. The revised questionnaire was administered to another group of students. A revision based on analysis of these responses led to the questionnaire shown in Appendix A. This version has been used in our data collection.

The students involved in this study were enrolled in five different high schools. Three of the high schools were located in rural areas; one in a city and one in a small town. Questionnaires were administered to students in grades 9-12 at the end of the Spring Semester of the 1995-96 academic year.

Interpretation of Students' Responses

A total of 239 high school students participated in the survey. Table 1 shows the students'grade distributions by year in school.

Table 1: Students year in school

(N=239)	Grade Level				
	9th Grade	10th Grade	11th Grade	12th Grade	Other
% of Students	29	21	37	12	1

As shown in Table 2, most of the students in all grade levels were taking or had taken a physical science course at the time of our survey. The majority of 11th and 12th graders were taking Chemistry. Almost half of the 12th graders and a few 11th graders had taken or were enrolled in the high school physics course.

Table 2: Percentage of students who were taking or had already taken some selected science courses across the grade levels

Courses Completed or Enrolled In				
	Physics	Physical Science 1-2		Chemistry
9th Grade	--	76%	80%	2%
10th Grade	-	51%	53%	10%
11th Grade	6%	66%	65%	77%
12th Grade	44%	31%	31%	86%

Categorization of the Students Responses

As a first step, a panel of physics education researchers identified categories by analyzing the student responses. These categories were based on three principles (Marton, 1986; Bowden et.al., 1992; Prosser and Walker, 1995).

- Categories should be extracted from the student responses; thus we can not have pre-assigned categories.
- Categories should not be mutually exclusive or inclusive, but distinguishable.
- Responses must be explicit to be categorized.

In identifying categories the panel members used an iterative process.

Using the responses from fifty randomly selected questionnaires, the panel identified a set of tentative categories. Then, using these categories each panel member individually sorted all responses. Disagreements about category descriptions or allocation of students' responses to categories were resolved with reference to the students' responses as the only evidence of students' understanding. Then, the panel revised the categories and established a set of rules for placing all responses in categories.

To check consistency the panel members sorted another 25 randomly selected questionnaires. The consistency of 0.82 was acceptable for this type of study. Then, a second panel placed another set of randomly selected responses in the categories established by the first panel. With one exception this panel had a similar level of consistency. After a minor modification to account for the exception, the categories were used for the entire sample.

Brief Descriptions of the Categories for the Descriptions of Atoms

This process resulted in six primary categories for the student responses to the question, "Describe an atom." The three of these six are generic: no response, “do not know,” and “other”--a response that does not fit in the existing scheme but occurred too seldom to be established as a category.

The remaining categories are as follows:

- *Units of matter*: The student defines the atom as a constituent of matter. For example, “Atom makes up stuff, building block of everything, the smallest unit of matter.”
- *Constituents of an atom*: The student states constituents of an atom and perhaps their location. For example, “An atom contains electrons, protons, and neutrons. A nucleus may be found in the center.”
- *Model of an atom:* The student describes some atomic model. For example, “An atom is made up of a nucleus with protons and it has electrons that circle around it....”

Each primary category was further divided into subcategories. The full descriptions and numerical codings are described in Appendix B.

In keeping with the phenomenographical approach these categories, except for no response and do not know, are not mutually exclusive. A student's response could be placed in two or, even, all three major categories. For example, the response, “An atom is the smallest unit of an element, has protons, neutrons, and electrons and looks like a small solar system.” would be placed in all three categories.

The phenomenographical approach also enables us to establish a hierarchy within the categories. The major categories have a hierarchy from lowest to highest of Units of Matter, Constituents of Atoms, and Models of Atoms. Combinations of categories also fit in the hierarchy. Table 3 indicates the hierarchical structure of the categories and their combinations

Table 3: Hierarchical Structure of the Categories.

Highest level is at the top of the list.

Units, Constituents & Model
Constituents & Model
Units & Model
Model
Units & Constituents
Constituents
Units of Matter

The question about seeing an atom is multiple-choice and thus required only a straightforward analysis.

The responses to the question about energy from an atom were also approached using phenomenology. However, the classifications were much simpler. Our primary categories were "Yes, but I don't know how," nuclear energy, motion, other, and no energy. We were unable to assign a hierarchy to these categories.

An Example of Categorization of a Student Response

As an example of our method consider the student response presented below. The student's answers are printed in italics with brackets added by us to facilitate discussion.

Question 1: Using words and/or diagrams describe your ideas of an atom. Include in your description what an atom is and how it is related to other objects.

"*An atom is the* [*smallest part of matter; atoms make up everything] and* {*are made up of protons, neutrons and electrons*}" The drawing shown in Figure 1 was included.

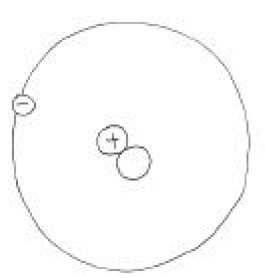


FIGURE 1: Student representation of an atom

The part of the response in square brackets […] falls into the units of matter sub-category "smallest unit of matter" (coded 2-2). The part in {…} falls into two constituents sub-categories one for identifying the electron, proton and neutron (coded 3-2 epn) and another for their location (coded 3-3). Finally, the drawing places the response in the atomic models sub-category planetary model (coded 4-2).

Question 2: How can an individual atom be seen? (Check all that apply)

The student checked only: "*Atoms can not be seen now, but may be seen with some invention of the future.*"

Question 3: Is it possible to obtain energy from atoms? If yes, briefly explain how.

"*Yes, some atoms are radioactive, and when the nucleus is unstable, it may emit a particle and produce energy.*"

This response to question 3 falls into the category "nuclear energy" (coded 5).

Each student's responses were analyzed using a similar procedure.

The analyses of student responses to the first question "Using words and/or diagrams describe your ideas of an atom. Include in your description what an atom is and how it is related to other objects." are given below.

Units of Matter (26%)

Responses in this category described an atom in terms of its relation to matter.

This category is the lowest one in the hierarchical sequence, because students wrote about only one aspect of an atom, its relation to matter. The following statements are examples of this category.

- "Atoms are really small things no one has ever seen and everything is made of some sort of atom."
- "An atom is very small. It is the building blocks of all things."

Most of these students concentrated on the size of the atom. To understand the meaning of small or the smallest, we need to look at the students' responses to the second question where students were asked how an individual atom could be seen. This information will be discussed in the next section

Units of Matter and the Constituents of an Atom (7%)

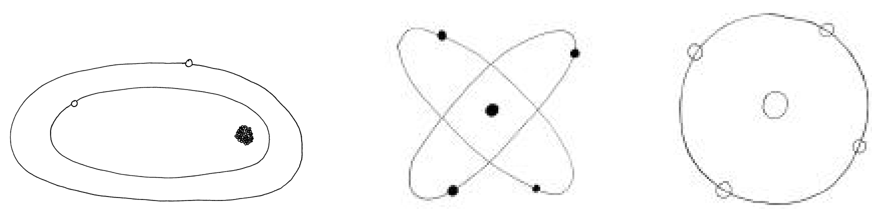
A response is placed in this combination of categories when the student not only defines the atom but also states the constituents of an atom. The focus of the student is on both the constituents and the relation of an atom with matter. The following statements are examples of students' responses.

- "Atoms are made up of electrons, protons, and neutrons. Atoms make up everything."
- "Atoms are the building blocks of molecules. Each atom has a certain number of protons, electrons, and neutrons. Atoms combine with other atoms to form the objects we are familiar with today."

These extracts are evidence that students heavily concentrate on the constituents and on the relation between the atom and macroscopic world.

Units of Matter and Models of an Atom (3%)

Responses in this combination of categories are from students who define the atom by drawing or describing a model of an atom, but where the constituents are not mentioned. However, each student mentioned the atom as a form of matter. The examples in Figure 2 are taken from the students' responses. From these drawings it is evident that students have some idea about the atomic models but they fail to identify the constituents of an atom.



(a) (b) (c)

FIGURE 2: Students' representation of an atom

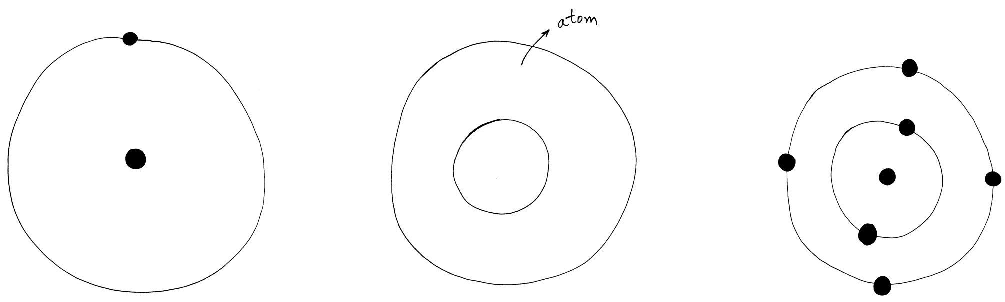
For Figure 2 (a) the student wrote "atoms make up everything around us". For Figure 2 (b) the student responded that "an atom is a tiny particle of matter that is combined with other atoms to make large objects." The student who drew Figure 2 (c) described the atom as the "smallest particle of matter".

Constituents of an Atom Only (5%)

In these responses, the students identified the objects that are in an atom but did not discuss the atom's relation to matter or an atomic model. One student responded with "proton, neutron, electron”. Another said, “An atom contains electrons, protons, and neutrons. A nucleus may be found in the center.” No information is given about the relation of an atom to the matter even though it was requested explicitly.

Only Models of an Atom (3%)

The students in this category drew a picture of an atom without any description. They did not mention the constituents of an atom and its relation with matter. The representations of an atom in Figure 3 are taken from the students’ responses.



(a) **(b)** **(c)**

FIGURE 3: Students’ representation of an atom. These drawings were not accompanied by any description.

Constituents and Models of an Atom (20%)

To be placed in this combination of categories students described what objects make the atom and expressed the relation between these objects with a model. In this category, students have higher level conceptions of an atom than previous categories. The following descriptions are examples of students' responses.

> "An atom has protons and neutrons in its nucleus. The protons are positively charged which the neutrons are neutral. The electrons orbit around the nucleus in energy levels. The electrons are negatively charged." This description included Figure 4.

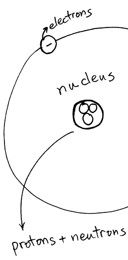


FIGURE 4: A student's representation of an atom, which was part of a description.

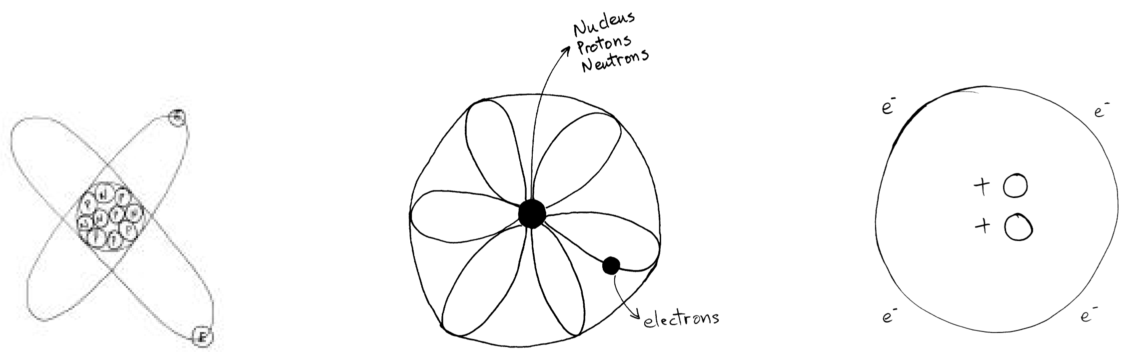


FIGURE 5: Students' representation of an atom. Neither a description of an atom nor their relations with matter were included by this group of students.

It is evident from these figures that students have identified the constituents of an atom and presented it with a planetary type model.

The units of matter, constituents, and atomic models (14%)

This category is the one with the highest rank in our hierarchical order because students mention the all three characteristics of an atom. The following are examples for this category.

> "An atom is the simplest unit of a substance that retains the properties of that substance. An atom has a positively charged nucleus that contains protons (+) and

neutrons (no charge) surrounded by electrons which are randomly wound the nucleus (there is a given probability of their position).” This description included Figure 6.

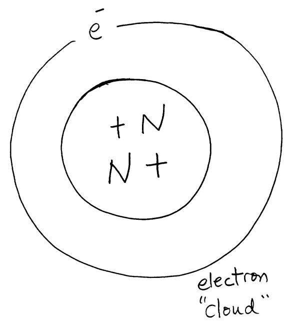


FIGURE 6: This student representation included a description that mentioned probabilities.

Other students wrote

- “An atom is the building block of all matter. It is the smallest coherent part that an element may be broken down into and still retains its properties. It is made up of electrons, neutrons, and protons. The neutrons and protons constitute the nucleus, and the electrons orbit the nucleus.”
- “Other objects are made up of atoms; atoms are what forms matter. Atoms are made up of an electron cloud that contains electrons and a nucleus that contains protons and neutrons. Atoms lose electrons and gain them to become positively or negatively charged.”

This latter student clearly defines the atom in terms of its constituents and its relation to matter; then he/she explains their relation in electron cloud model without any specific attribution to the probabilistic nature. From this respond we can not state what this student conception of an “electron cloud” is.

Some of the students have a shell model representation of an atom as shown in the following example:

“An atom is the single smallest piece of matter. It has a nucleus and contains protons and electrons. It is very small. It has shells of electrons called orbitals.”

This description includes Figure 7.

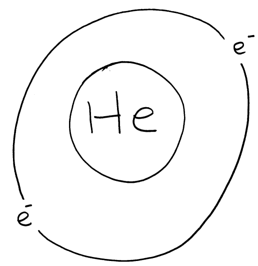


FIGURE 7: Representation of an atom given by a student who discusses orbitals.

Even though many students are fairly successful in describing the atom in terms of its relation to matter and its constituents, the models presented here are not quantum mechanical representations. A few students do use terms such as "electron cloud" and "orbital" which are used in quantum mechanical descriptions. However, we did not ascertain the students' definitions of these terms.

A summary of results for all categories by grade level is given in Table 4.

Table 4: Students' distribution in each category or combination of categories across the grade levels

	Grade level			
	9th Grade	10th Grade	11th Grade	12th Grade
Units, Constituents & Model	20%	12%	10%	15%
Constituents & Model	26%	16%	16%	27%
Units & Model	4%	2%	3%	3%
Model	3%	6%	2%	-
Units & Constituents	9%	2%	10%	-
Constituents	6%	4%	3%	6%
Units of Matter	11%	33%	36%	24%

No Response

Only 24 students out of 239 students did not respond to question 1. We have no information about why those students did not respond.

Do not know

Responses in this category are from students who responded to the question explicitly that they did not know the description of an atom and its relation to matter. This category has only twelve students.

Other

In the "Other" category are the responses that did not fit the categories but were too few in number to warrant the creation of another category. 5% of the responses fall in this category. Examples are:

"The smallest living form of life. If you did not have atoms, you wouldn't be alive."

"Atoms can be dangerous if used in the wrong way."

"A world destroying bomb."

Overview of Results for Description of the Atom

Figures 9 and 10 present a summary of all data collected in this study. Except for ninth graders more students fall in the units of matter than any other category. However, none of the categories or combination of categories exceeded the 25% of students. More than half of the students included "Units of Matter" response in their description whereas only 33% of students mentioned something about the constituents, and 42% of students included atomic models in their descriptions.

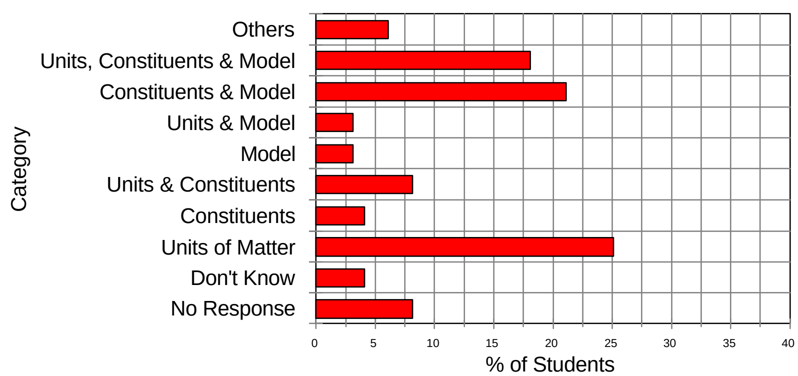


FIGURE 9: Percentage of Students in each category or combination of categories across Grade Levels

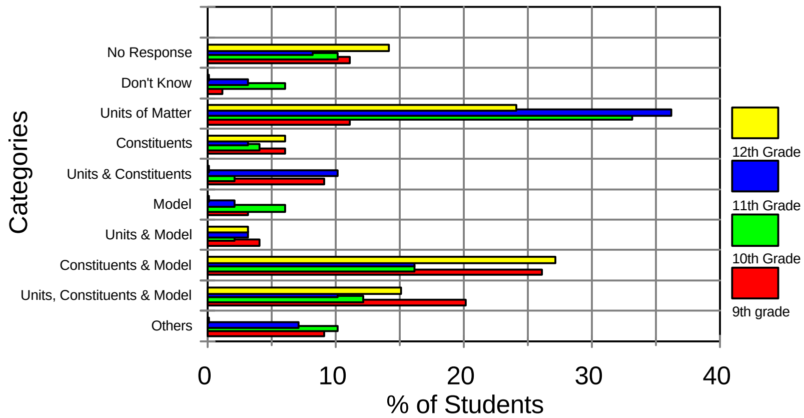


Figure 10: Percentage of students whose responses were placed in each category.

Results by Category of Description

As shown in Figure 9 students' distribution across the category "units of matter" and combination of categories "constituents and model" and "units, constituents and model" is different than the rest of the categories. More than 15% of students fell in this category or combination of categories whereas less than 10% students fell to the rest of the category or combination of categories.

Results by Grade Level

The 10th and 11th graders more often described an atom as a unit of matter than any other grade level students. In this category, students concentrated on the size of an atom and its relation to matter. Though students mentioned the size of an atom as very small, we have no further information about whether they are associating some macroscopic properties to the individual atoms as reported by Anderson and Renstrom (1983, cited in Griffiths and Peterson, 1992). Since most of our students thought that an atom could be seen with present technology, students may see an atom as something directly observable.

We found very little variation across the grade levels in students' descriptions of the constituents of an atom, models of an atom, and combination of categories of units of matter and models of an atom. For each group a small fraction of students fell in these categories.

There is a significant variation in the grade level distribution of students in combination categories of constituents and models of an atom. The 9th and 12th grade students described an atom by concentrating on constituents and models of an atom more than the 10th and 11th grade students.

In our interpretation the highest hierarchical level of description is the combination of all categories. In this combination of categories, students described an atom by including the units of matter, constituents, and models of an atom. The 9th graders differed from others in this category. One reason could be that 76% of 9th graders have taken physical science course and 80% of them were enrolled in another physical science course at the time of survey. These courses include a discussion of the structure of matter. Very few of the 9th graders had taken or were taking any other science course. We can not be certain that this course is the only source for the description of an atom by 9th graders. Some other sources may also contribute to their description such as retained knowledge from earlier school years, television or books.

In the combination of categories, students concentrated on three features of an atom:

(1) how big an atom is and its relation to matter

(2) constituents of an atom and their approximate location.

(3) models of an atom that varied from the one similar to the Thomson model of an atom to some terminology of quantum mechanics.

Because the same features were absent in the descriptions submitted by students in most other grade levels, we suspect that this description comes from course content.

Most students in higher grade levels reported that they had completed physical science courses similar to the ones being completed by the ninth graders. Yet, they did not, on the average, give responses at as high a level as the ninth grade students. This result seems consistent across schools in the sample. We tentatively conclude that the more complete descriptions of the atom are the result of contemporary instruction and not remembered later.

Students' Perceptions of Seeing an Atom

The percentages of students' responses to the question about whether an atom can be seen now or in future are shown in Table 5. The data show that about 69% of all students except 9th graders indicated an atom could be seen with present technology. However, 9th graders think that an atom will be seen in future with some invention. Only a few students think that seeing an atom is not a technological possibility.

Table 5: Percentage of students falling in categories of how an atom can be seen across the grade levels. (Numbers totaling less than 100% indicate that some students did not answer.)

An atom can be seen:	9th Grade	10th Grade	11th Grade	12th Grade
with Present Technology	18%	69%	69%	72%
with Future Technology	61%	14%	14%	21%
Impossible Even in Future	8%	2%	10%	3%
Other	13%	2%	3%	-
	100%	87%	97%	96%

How Students Relate an Atom with Energy

The data show that a majority of students think that it is possible to obtain energy from an atom. Most often nuclear energy is stated as the way to obtain energy from an atom. The “other” category includes various ways to obtain energy from an atom such as electromagnetic radiation, electricity, and chemical reactions. A few students thought that electrons produce energy. Furthermore some students mentioned that atom “smashing” and/or particle accelerators are the way to obtain energy from an atom.

Table 6: Percentage of students relating an atom with various type of energy across the grade levels

Category	9th Grade	10th Grade	11th Grade	12th Grade
No Response	17%	16%	8%	7%
Do not Know	4%	2%	3%	3%
No Energy	13%	12%	13%	3%
Yes, but don’t know how	4%	6%	13%	10%
Nuclear Energy	31%	31%	26%	24%
Motion	3%	4%	10%	10%
Others	27%	29%	27%	41%
	99%	100%	100%	98%

Conclusion

In describing the atom, most of the students fall into our low hierarchical level of reasoning categories. Forty-six percent of 9th graders fell into the combination of categories "constituents and models" or "units, constituents and models" whereas twenty-eight percent of 10th graders and twenty-six percent of 11th graders fell in these combinations of categories. Because the higher grade level students had completed courses similar to those of the ninth graders, we conclude that students do not seem to retain what they have learned from previous courses or years. Majority of students did not include a model in their descriptions of an atom. Students, who included a model in their description, used mechanical models in their descriptions whereas 3% percent of them mentioned some quantum mechanical concepts.

The data show that about 69% of all students except 9th graders indicated an atom could be seen with present technology. However, 9th graders think that an atom will be seen in future with some invention. From students' responses to the questions 2 and sometimes 1, we can conclude that most of the students perceived an atom as something very small, but still directly observable. They are not clear about the size of the micro-world.

Sixty-six percent of 9th graders, seventy percent of 10th graders, seventy-six percent of 11th graders and eighty-seven percent of 12th graders think that it is possible to obtain energy from an atom. This indicates that grade level has effect on students' responses in relating the concept of energy and atom.

Even though students related an atom with energy, this is not within the context what is given in their textbooks where electronic transitions were associated with the energy. Most often nuclear energy is stated as the way to obtain energy from an atom.

Implications for Future Study

The next step in understanding students' views of atoms is an interview for further understanding of students' ideas about the atom. From these data, we need to create an interview protocol and interview with students so that we may learn what they meant by writing terms such as "electron cloud" or describing a probabilistic picture. We need to probe the students' ideas about which macroscopic properties they are associating with an individual atom. Furthermore, we need to probe in what context students' prefer to use different models. How students are affected with the availability of different models to them is another big issue that we need to learn from these interviews. We also need to find out if omissions of certain aspects from their descriptions, such as the nucleus, are significant or just a simple omission.

We need to find out why students believe that with present technology we can see an atom and what they mean when they say an atom can be seen. From there we can compare students' model of an atom with students' perception of size of an atom. By this understanding we can help students to construct a better relation of an atom with matter.

We need to probe them about the energy from an atom. When these students discussed energy from an atom, they most frequently mentioned nuclear energy. Is the equality of nuclear and atomic energy related to cultural background? In order to address this question, we will compare responses about energy from atoms of the US students with a sample of South African and Romanian students.

We also need to make a direct comparison with the work of Niedderer and Bethge (1996). They report that a very large fraction of their sample of German students drew a Bohr model. However, in their questionnaire they asked students to draw ("zeichnen") an atom where we used the word "describe." Understanding how this slight difference in wording leads to very different results could help us understand the process by which students come to understand models of the atom.

Implications for Teaching

Teachers can use the results of study in various ways. For example they can build on the small unit of matter idea. They can change the emphasis on the topics for better understanding of constituents of an atom. The results of this study imply that teachers and curriculum developers who want to use quantum mechanical approach and do not wish to include the Bohr Model can safely do so. A large fraction of students do not describe the atom in terms of a planetary or Bohr model. Thus, teaching contemporary physics without making a transition from the semi-classical Bohr picture to quantum mechanics seems justified.

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APPENDIX A: THE SURVEY INSTRUMENT

Some Questions About Atoms

Please take a few minutes to answer the questions below.

1. Using words and/or diagrams describe your ideas of an atom. Include in your description what an atom is and how it is related to other objects.

2. How can an individual atom be seen? (Check all that apply)

- ❑ with our unaided eyes
- ❑ with an ordinary (optical) microscope
- ❑ with an electron microscope
- ❑ with some complex apparatus but I don't know what it's called
- ❑ Atoms cannot be seen now, but may be seen with some invention of the future.
- ❑ Humans will never be able to see atoms.
- ❑ Other (Please specify____)

3. Is it possible to obtain energy from atoms? If yes, briefly explain how.

4. a) What grade are you in? 7 8 9 10 11 12

   b) What year college are you? Freshman Sophomore Junior Senior

5. What science class are you taking now?

6. What science classes have you taken in the past?

APPENDIX B: CATEGORIES AND CODING SCHEME

Code & Category
0 No response
1 I don't know
2 Units of Matter
2-0 Just units of matter
2-1 Atoms are small units of matter
2-2 Atoms are the smallest unit of matter
2-9 Other
3 Constituents of atoms
3-1 All constituents mentioned
3-2 Some constituents mentioned
Indicate which ones (e.g. 3-2ep for electron and proton but not neutron mentioned)
3-9 Other
4 Model of atoms
4-0 Model similar to the Thomson Model of the Atom
4-1 A mixture of the Thomson Model and a planetary model
4-2 Planetary Model
4-3 Bohr or Shell model
4-4 Quantum Mechanical Model or some statement of probabilities
4-9 Other
5 Other