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*The present trend in the design of physics courses is to place emphasis on understanding rather than the rote memory of ideas and processes.*

*The development of systematic approaches to direct thought patterns decreases the memory burden.*

*The process of variation provides a universal thought pattern that can be applied in almost all phases of physics.*

*This paper provides a brief description of some selected sample applications. It is hoped that these will illustrate the scope and the merit of this approach.*

The present trend in the design of physics courses is to place emphasis on understanding rather than rote memory of ideas and processes. The development of understanding on the part of each individual is a complex undertaking. There are some basic guidelines that seem to have merit in the design of a course for understanding.

The organization of the knowledge in evolving conceptual schemes rather than fragmented units provides continuity. The relating of similar ideas decreases the memory burden. The development of systematic approaches directs the thought patterns. It is the last of these guidelines that will serve as the topic of this report.

The relationship between variables and the operation with variables and constants serves as a system that has almost universal application.

This paper presents a brief description of the use of variation as an approach to thought processes as developed and used in the design of a high school physics course at the Price Laboratory School, University of Northern Iowa at Cedar Falls, Iowa. An understanding of variation and the operation with variables and constants is introduced early in the course. The process of variation is then used to develop understanding in each of the developmental schemes. Some selected examples of the use of variation are presented to indicate the scope and potential of this approach.

A brief description of the activities and learning experiences which have preceded the introduction to variation will serve to indicate the approach being used.

Before becoming involved in the process of variation, the students have participated in a variety of learning experiences related to models and operations with these models. The scope of models, types of models, transforms of models, and the correspondence between models has been presented. The laboratory activities have provided direct experiences with image, diagram, structural, graph, sentence, and descriptive models. The students have had experiences with representations and instructions which are coded into the models. Dimensional operations have been developed through a set of meaningful experiences.

The principles of variation are introduced by developing an understanding of related variables and constants. The variables then can be classified as number quantities, scalar quantities, and vector quantities. Number quantities have only a number part. Scalar quantities are defined as quantities that have a number part and a dimension part. Vector quantities have a number part, dimension part, and a direction part. The number and dimension parts are often combined and referred to as the magnitude of the quantity. Vector quantities can then be defined as being composed of a magnitude and a direction; scalar quantities have magnitude only. The processing of scalar quantities requires operations with both the number part and the dimension part. Vector quantities require the operation with the number part, the dimension part, and the direction part of the quantity.

Dimensional operations often produce a dimension that is the ratio of two identical dimensions. The dimension obtained for radian measure can be the ratio of two identical dimensions. Radian measure is defined in terms of the ratio of the arc distance and the radius. This ratio may be considered as a number quantity if the unit of length for the measurements is the radius. Even in this case the dimension radii could be attached to the radius distance and the arc distance. If the symbol ϒ is used to represent the length of the radius then the radians in one revolution $= \frac{2\Pi\Upsilon}{1\Upsilon}$

$= \frac{2\Pi\Upsilon}{\Upsilon} = 2\Pi$ radians.

The dimension $\frac{\Upsilon}{\Upsilon}$ is a ratio of identical dimensions. The radian example is more illustrative if the radius and the arc distance are each measured with one of the standard units of length. (Vs. cm). The dimension of radians then becomes $\frac{cm}{cm}$. This is a ratio of identical dimensions or an identity ratio.

The confusion results from our attempt to communicate and to operate with these identity ratio dimensions. The common practice has been to refer to quantities with identity ratio dimensions as being without dimension. This is misleading as there are "pure number quantities" that are also without dimension. It would be more meaningful to refer to these identity dimensions as unity dimensions. There are a number of arguments to support this contention. Identical number ratios and also symbol ratios are referred to as unity. The number one is often used to replace these ratios. It seems logical to refer to identical symbol ratios as unity and to replace these with the number one. The dimensions $\frac{radians}{seconds}$ can be written as $\frac{1}{sec.}$ or $sec.^{-1}$. The replacement of unity dimensions by the number one works well in all operations with dimensions.

The student should understand that the constant of variation must be included in the operation unless the number values and dimensions of the variables are selected so that the constant of variation has a number value of one and a unity dimension.

A simple example will illustrate the inclusion or exclusion of the constant of variation from a sentence model and the subsequent operations. The three variables distance, speed, and time are usually related by the model $D = vt$. The constant of variation has been omitted from this sentence. An analysis of this model will demonstrate that the dimensions selected for the variables result in a constant of variation that has a number value of one and a unity dimension.

To demonstrate this the model is written with the constant of variation included. This model is $D = Kvt$. The corresponding descriptive model states that the distance varies directly as the speed and directly as the time. This model can be transformed to a model for K ($K=\frac{D}{vt}$). If the dimensions selected are D (cm), t (sec.) and v $\left(\frac{cm}{sec.}\right)$ then the dimensions of K are $\frac{cm}{\frac{cm}{sec.} \times sec.} = \frac{cm}{cm}$. This is obviously a unity dimension. It is obvious that K also has a number value of one.

A problem involving a different set of dimensions will demonstrate the use of a constant of variation that is not unity and has a number value not equal to one.

Problem: Determine the number of miles one could travel in 2 hours if the average speed were 80 $\frac{ft.}{sec.}$.

The dimensions of the variables are D(mi.), t (sec.) and v $\frac{ft.}{sec}$. The model $K=\frac{D}{vt}$ is first used to determine the number value and the dimensions of K. The dimensions of K are $\frac{mi.}{\frac{ft.}{sec.} \times hr.}$ or $\frac{mi. \ sec.}{ft. \ hr.}$

The number value of K can now be determined from the dimension of K. 1 mile = 5280 ft. and 1 hour = 3600 sec. The number value of K can be determined by substituting numerical values for the dimensions.

$$K=\frac{Mi \ sec}{ft. \ hr.} = \frac{1 \times 3600}{5280 \times 1} = \frac{360.}{258}$$

Then $K = \frac{360}{258} \frac{mi. \ sec.}{ft. \ hr.}$

With the value of K determined the model $D=Kvt$ can be used to determine the value of D.

$$D = \left(\frac{360}{258} \times 80 \times 2\right)\left(\frac{mi. \ sec.}{ft. \ hr.} \times \frac{ft.}{sec.} \times hr.\right)$$

or D = approx. 138 miles.

This operation required that the constant of variation be included in the model and that the number value and the dimension of the constant of variation be a part of the operation.

The process of variation finds extensive application in all phases of physical science; variation serves as an organizer of many of the thought processes. It also provides a valuable tool to aid in the development of concepts. Some selected, illustrative examples will be presented to demonstrate the scope of this process. These examples are illustrative and not inclusive.

In the evolving conceptual scheme of acceleration the students develop models that relate acceleration, time, space, and speed. The next development involves the factors that determine the amount of acceleration. This is introduced through the historical account of what scientists believe about the acceleration of falling bodies. It is assumed that the student accepts the idea that all objects fall toward the earth with the same acceleration, regardless of the mass of the object, if air friction is neglected.

According to the principles of variation this identical acceleration of different masses falling toward the earth would fit the model $A = K\frac{F}{M}$ or the acceleration is directly proportional to the accelerating force and inversely proportional to the mass being accelerated. This becomes a tentative model.

The next project involves some laboratory measurements to determine how well the model $A = K\frac{F}{M}$ fits the data collected.

This will be done by reducing the number of variables from three to two. If M remains constant then $\frac{K}{M} = K_1$ and the model reduces to $A = K_1F$. This model requires a piece of apparatus for which the mass being accelerated remains constant as a variable force is applied.

The apparatus used is a version of the Atwood's Machine. Two plastic bottles are connected by a piece of monofilament. This monofilament passes over two small, nearly frictionless pulleys. The bottles are loaded with water and the system is friction compensated so that the accelerating force is zero. 10 ml. of water are then transferred from one bottle to the other bottle. This provides an accelerating force of approximately 20 grams. An electronic timer activates an impulse counter. This provides a reasonably accurate measurement of the time interval required for the system to move a measured distance. The acceleration is then calculated by using the model $A = \frac{2s}{t^2}$. If another 10 ml. of water is transferred, an accelerating force of approximately 40 grams can be obtained. This process is repeated for accelerating forces of 60 grams, 80 grams, etc. In each case the water is not removed from the system so that the mass remains constant. The ratio of $\frac{A}{F}$ remains constant within the limits of experimental error.

If the quantity F remains constant then the quantity KF remains constant. The model $A = K\frac{F}{M}$ reduces to $A = \frac{K_2}{M}$ or $AM = K_2$.

The bottles are filled with water with enough difference in weight to obtain a measurable acceleration. The mass of the system is determined and the acceleration is measured. To reduce the mass while keeping the force constant, 100 ml. of water are removed from each bottle. This reduces the mass by approximately 200 grams. The product of AM remains constant within the limits of experimental error.

The experimental results support the validity of the model $A = K\frac{F.}{M}$

The next development is the elimination of the constant of variation from the model so that this model can be written and applied in the form $A = \frac{F.}{M}$

The constant of variation can be omitted if this constant has a number value of one and a unity dimension. This will require the appropriate selection of number values and dimensions for the quantities A, F and M. There is a methodical way in which this selection can be made.

The model is written without the constant as $A = \frac{F.}{M}$ The number values and dimensions of two of the quantities are selected. The number value and the dimensions of the third quantity are then made to conform to the values selected. The usual procedure is to let the values of F conform to the values selected for A and M. The model is written as $F = MA$. This form indicates that the dimensions of F must equal the dimensions of the product of mass and acceleration. The number value of F must equal the number value of the product of M and A.

This provides an unlimited set of number values that will fit the number requirement. The most obvious set is $A = 1$ $F = 1$ $M = 1$.

There are numerous dimensional combinations that will fit the dimension requirement. A few examples will illustrate the process. If $A = \frac{cm_2}{sec.}$ and $M = g$ then $F = \frac{g\ cm_2.}{sec.}$ This force which is known as a dyne is that force that will cause one gram of mass to accelerate at the rate of one $\frac{cm_2.}{sec.}$ A similar development can be used for the newton $\left(\frac{Kg\ M}{sec._2}\right)$ and the poundal $\left(\frac{ft.\ lb.}{sec._2}\right)$. The students are encouraged to list many combinations. One unusual contribution was $F = \frac{brick\ mile.}{micro\ sec.\ century}$

The student was able to define one unit of force as the force that would change the velocity of one brick at the rate of one mile per micro second each century.

The process of variation can be used to determine the ratio between gravitational units of force and absolute units of force.

A gram of force is defined as the force which gravity exerts on a gram of mass. The acceleration produced by a gram of force is the acceleration of gravity (approximately 980 $\frac{cm}{sec._2}$ at the surface of the earth).

The dyne of force accelerates a gram of mass at the rate of 1 $\frac{cm}{sec._2}$.

From the model $F = KA$. for a constant mass, it can be inferred that a gram of force is approximately equivalent to 980 dynes of force.

Another example of the use of variation in model building is provided by the analysis of the model for the natural frequency of the fundamental of a vibrating string.

Most physics texts state the model as $N = \frac{1}{2L}\sqrt{\frac{F}{M}}$. The number of variables can be reduced to two by keeping the other variables constant. If F and M are constant then $NL = K^1$. If M and L are constant then $N = K_2 \sqrt{F}$ and if L and F are constant then $N\sqrt{M} = K_3$.

It is hoped that the illustrative examples will suggest the scope of the application of variation as unifying systematic approach to physics. The author has found this to be a very effective tool.

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## Convention Plans Near Completion

Plans are nearing completion for the 1969 NSTA convention in Dallas, March 21-25. A tentative convention program has been compiled with confirmed arrangements for the majority of sessions, seminars, and workshops.

Among the activities on the program are two series of science teacher workshops scheduled for Friday, March 21, and Tuesday, March 25. These workshops provide opportunities for approximately fifty teachers in each one to work directly with a variety of commercial instructional materials in a laboratory-type setting. Among the twenty workshops that have been scheduled, five are for elementary teachers, seven deal with junior high school science education, and the remainder are directed to teachers of science at the senior high school and college levels.

## Preliminary Planning Session for Short Course

Preliminary plans for the Science Teachers' Short Course were discussed at a meeting at Iowa State University, Ames, on December 7, 1968.

Present were several of the science department heads with Dr. Donald Biggs acting as coordinating chairman and Sister Barbara Donovan representing the ISTS.

The Short Course is scheduled for Friday and Saturday, March 7th and 8th. The general format will be similar to that of past years although some minor changes will be made in response to suggestions made by participating teachers last year.

Generally, the special symposia held on Friday and Saturday will be in the areas of biochemistry, biology (including botany and zoology), chemistry, geology, metallurgy and physics. The addition of a math and computer science section was also considered.

A general letter of announcement will be issued by Dr. Biggs in January and programs and reservation forms will be available by early February.