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Discovery of Ambiguity in the Traditional Norms of Specifying Physical Quantities along the Axes of Coordinates in Drawing Data Based Graphs

Pramode Ranjan Bhattacharjee

Retired Principal, Kabi Nazrul Mahavidyalaya, Sonamura, Tripura 799131, India

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Abstract This paper (falling within the purview of Physics Education Research in particular, and Science Education Research in general) deals with a very significant issue related to labeling of the physical quantities along the axes of coordinates in graphing. It has been discovered that the traditional norms of specification of physical quantities along the axes in graph drawing are ambiguous. Such norms of specification totally ignore the inherent nature of a physical quantity. Furthermore, as a result of such a specification, each coordinate of a point lying on the graph assumes a numerical value along with a unit tagged with it, thereby violating the most fundamental concept of Cartesian coordinate geometry according to which the coordinates of a point in two-dimensional real space should be an ordered pair of real numbers. To get rid of such an ambiguity, an unambiguous procedure of specifying the physical quantities along the axes of coordinates in graph drawing has been finally proposed. The issue raised in the paper along with the relevant solution offered are both original and novel, never considered by any one earlier and hence the present scheme could not be placed into context to other existing works on the same issue. However, the present work has been compared with two other earlier works reported by the author in relation to graphing to judge its novelty and originality.

Keywords Cartesian Coordinate Geometry, Coordinates of a Point, Data Based Graph Drawing, Theoretical Data Based Graph, Experimental Data Based Graph

1. Introduction

Graphing or graph drawing is an indispensible part of scientific study and research. The patterns and trends of data can be visualized with the help of Graphs. In other words, graphs help to visually illustrate relationships in the data. That is why scientists are always in need of representing data in graphical form. Depending upon the importance of graphs from the view point of scientific interest, it is always essential to see that a graph drawn is easily readable, self-explanatory, and free from any kind of ambiguity so that it must enhance rather than confusing any one about the understanding of scientific study and research. Apart from many other qualities, a good graph should have: (i) a well-defined title, (ii) clear indication of the X- and Y- axes of coordinates, (iii) the independent variable plotted along X-axis, and the dependent variable plotted along Y-axis, (iv) a well-defined labeling along each of the two axes of coordinates, (v) data points, which could be clearly identified and are not covered up or obscured, (vi) well-defined proper scales used along the two axes of coordinates.

The fact that misleading graph titles exist in many places of the traditional scientific literature has been observed and a discovery in the said context has been reported in [1]. After pointing out the existence of such ambiguous graph titles, it has been emphasized in [1] that each of those ambiguous graph titles should be replaced by the unambiguous ones in a manner as has been proposed in [1] to enhance the quality of graphing. Furthermore, it has been found that the traditional procedure employed for drawing enlarged graph by making use of two different scales along the two axes of coordinates is flawed on account of the fact that such a procedure of drawing an enlarged graph violates the fundamental concept of "Enlargement" in Transformation geometry [2]. A further discovery in the said context along with a procedure of drawing an enlarged graph without violating the fundamental concept of "Enlargement" in Transformation geometry has been reported in [3].

After going through long-used literature search, it has been found in the present study that the very manner in which two relevant physical quantities are specified along the two axes of coordinates for drawing a graph is totally ambiguous. This is because each of those procedures of specification of two physical quantities along the two axes of coordinates in graph drawing primarily ignores the inherent nature of a "Physical quantity", which has got a numerical value along with a corresponding unit, or more precisely, as per Quantity calculus [4,5],

$$\text{Physical quantity} = \text{Numerical value} \times \text{Unit}$$

At the same time, on account of such a labeling of the physical quantities along the two axes, each coordinate of a point in the graph appears to have a numerical value along with a unit, which is always forbidden by the fundamental assumption of Cartesian coordinate geometry according to which coordinates of a point should be an ordered pair of real numbers.

To get rid of such type of ambiguous approaches in graphing, an unambiguous approach in relation to specification of two relevant physical quantities along the two axes of coordinates has been finally proposed.

2. Definitions and Preliminaries

Variable

A quantity which may take up different values in the course of a discussion is called a variable. In other words, a variable is a symbol that may assume any value within a given range. In any scientific discussion, a variable is denoted by a symbol or a letter.

Dependent and Independent Variables

Let $y = f(x)$ be a function of x, where x and y are two variables. Now, it can be easily seen from this functional relation $y = f(x)$ that corresponding to each and every value of the variable x, there will be a corresponding value of the variable y. Here, the value of the variable x can be assigned arbitrarily. But this is not so for the variable y. The value assumed by the variable y depends on the value of the variable x. So, in this case, i.e. in the functional relation $y = f(x)$, y is the dependent variable and x is the independent variable.

Coordinates of a Point

In two-dimensional Cartesian coordinate geometry, coordinates of a point are defined as an ordered pair of real numbers. The coordinates of a point are used to specify the position or location of a point lying on the two-dimensional plane defined by two mutually perpendicular axes of coordinates.

Slope

In Cartesian coordinate geometry, the slope of a straight line is defined as the tangent of the angle (measured in the anti-clockwise direction from the positive direction of the X-axis) which the straight line makes with the positive direction of the X-axis. Thus if a straight line makes an angle θ (measured in the anti-clockwise direction from the positive direction of the X-axis) with the positive direction of the X-axis, then the slope (m) of the straight line is given by, $m = \tan\theta$. In the language of calculus, the slope (m) of the tangent to the curve $y = f(x)$ at the point (x, y) is given by $m = \frac{dy}{dx}$.

It then clearly follows from the mathematical definition of slope that slope is a pure number having no unit for it.

Graph

Graph is a pictorial form of representation of numerical data and equations. Teachers of elementary, middle school and high school, as part of their mathematics curriculum, often use graphs to impart lessons on Graphing (Graphing functions). Basic concepts of plotting and graphing are developed among the novice students from the lesson imparted to them by their teachers throughout the K-12 curriculum. Graphs are usually drawn on a two-dimensional real space defined by the rectangular Cartesian coordinate system.

Physical Quantity

A quantity linked up to a property of a material or a system in physics which can be measured is called a physical quantity. For example, length, mass, time, temperature, electric current, etc. are all physical quantities. The result of measurement of a physical quantity is expressed by a numerical value followed by the corresponding unit of the concerned physical quantity.

It would be worth mentioning here an important fact that is usually overlooked in the traditional discussions for dealing with physical quantities. Statements like: (i) a body of mass "m", (ii) a force "F", etc. are often found to appear in traditional resources in physics. Now, if we first examine the statement "a body of mass 'm'", then a question that results from in-depth thinking for this case is: What is "m"? Is it exclusively the numerical value of the mass of the body in a particular system of units or does it represent the mass of the body along with a unit? The same kind of queries also awaits for the statement "a force 'F'", and so on. It thus appears that the aforesaid statements prevailing in the educational resources are totally ambiguous.

More precisely, the ambiguous statement: a body of mass "m", could be replaced by any one of the following two unambiguous statements: (a) Let "m" stand for the symbolic representation of the mass of the body, or (b) Let "m" be the numerical value of the mass of the body in a particular system of units. From the statement (a), it clearly follows that "m" in this statement represents the physical quantity mass. Similarly from the statement (b), it is also clear that "m" in this statement is exclusively the numerical value of mass in a particular system of units. Thus the statements (a) and (b) are totally unambiguous.

In a similar manner, it would be possible to replace each and every other ambiguous statement of the above types by its corresponding unambiguous statement. Prior to starting a theoretical discussion, it is essential to make use of unambiguous statements similar to those mentioned above for bringing clarity, preciseness and sophistication in the relevant field of study.

Quantity Calculus

Quantity calculus [4,5] or in true sense, the Quantity algebra, is an algebraic system to deal with quantities where the symbol of a quantity represents the product of the numerical value and its unit. Here the term "calculus" should mean in its broader sense "a system of computation" and it should not therefore be thought of in the ordinary sense of differential calculus and integral calculus of Mathematics.

In this algebraic system, the rules of ordinary algebra are equally applicable to quantities as they do to numbers and at the same time they are also equally applicable to units of measurement because the units by their very definitions are also quantities in their own right. Thus, in quantity calculus, a physical quantity is expressed in the form:

$$\begin{aligned}&\text{Physical quantity}\\&= \text{Numerical value of the physical quantity}\\&\times \text{Unit of the physical quantity}\end{aligned}$$

or, simply,

$$\text{Physical quantity} = \text{Numerical value } \times \text{Unit}$$

or,

$$\frac{\text{Physical quantity}}{\text{Unit}} = \text{Numerical value}$$

Interested readers may go through [4,5] to build up a more concrete idea about "Quantity calculus".

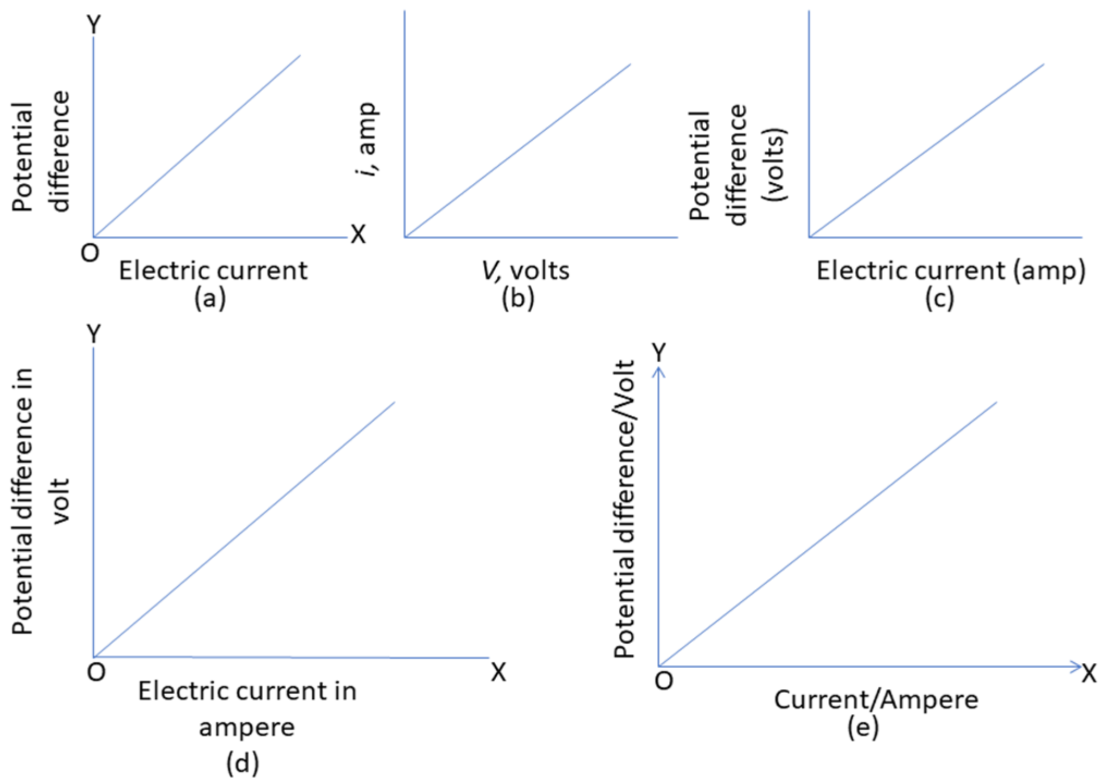

Figure 1. (a) Diagram showing the graphical nature of variation of potential difference across a metallic conductor with the change of electric current through it, (b) The current in a particular copper conductor as a function of potential difference, (c) Diagram showing the graphical nature of variation of potential difference across a metallic conductor with the change of electric current through it, (d) Diagram showing the graphical nature of variation of potential difference across a metallic conductor with the change of electric current through it, (e) Diagram showing the variation of Potential difference/Volt with the change of Current/Ampere for an Ohmic conductor

3. Traditional Approaches Regarding the Specification of Two Relevant Physical Quantities along the Two Axes of Coordinates in Graph Drawing

This section considers some of the approaches made in traditional literature regarding the specification of relevant physical quantities along the two axes of coordinates in drawing data based experimental or theoretical graphs.

First Approach

One of the approaches consists of specifying only the names of the two relevant physical quantities along the respective axes of coordinates. For example, the graphical behavior of the variation of potential difference across a metallic conductor with the change of electric current through it is represented in a manner as shown in Fig. 1(a).

This type of approach regarding the specification of the two relevant physical quantities along the axes of coordinates has been found to prevail at many places of the long-running literature, such as: in Fig. 2.33 (page 62) of [6], in Fig. 2 (page 57) of [7], in Fig. 2.1 (page 64) of [8], in Fig. 2 (page 204) of [9], in Fig. 1.1 (page 20), and Fig. 2.1 (page 40) in particular, and in almost all other Figures of [10], and so on.

Second Approach

An alternative approach like that shown in Fig. 1(b) in the aforesaid context has been found to be adopted in [11]. Labeling of the graphs shown in Fig. 1 (page 4/11), Fig. 3(a), (b), (c), (d) (page 5/11), and Fig. 4(a), Fig. 4 (b) (page 6/11) of [11] has been made in the same manner as shown in Fig. 1(b).

This type of approach regarding the specification of the two relevant physical quantities along the axes of coordinates has also been found to prevail at many places of the long-running literature, such as: in Fig. 3(a) and Fig. 3(b) (page 4) of [12], in Fig. 5 to Fig. 7 (page 6), Fig. 9, Fig. 10 (page 7) and Fig. 11, Fig. 12 (page 8) of [13], and so on.

Third Approach

Another mode of specification of two relevant physical quantities along the two axes of coordinates in traditional graph drawing is something like that shown in Fig. 1(c).

This type of specification has been found to exist in many traditional resources. The authors in [14] made use of this type of specification for the two relevant physical quantities along the two axes of coordinates in almost all diagrams of graphical representation prevailing in [14]. The graph appearing in Fig. 5 (page 219) of [15] also resembles the same type of specification of the two relevant physical quantities along the two axes of coordinates. Again, a similar type of specification of the two physical quantities has been found to remain present in Fig. 4 (page 4) of [16]. All graphical presentations have been made by the authors in [17] by following the same type of specification of the two concerned physical quantities along the two axes of coordinates. Furthermore, this approach of specification of two physical quantities along the two axes of coordinates has also been followed by the authors in [18] in the presentation of various graphs. The same norm of labeling physical quantities has also been followed by the authors in almost all the graphical presentations in [19].

Fourth Approach

Another mode of specification of the two relevant physical quantities along the two axes of coordinates in the manner as shown in Fig. 1(d) also exists in the long-running literature.

The graph displayed in Fig. 2.4 (page 21) of [6] is an example of this type of labeling of the physical quantities along the axes of coordinates. The same type of specification of the two physical quantities along the two axes of coordinates has also been considered by the authors in [20] in the graphical representation of experimental data. As a typical example, attention is being drawn to Fig. 5 (page 54) of [20] in the said context. The graphical representation shown in Fig. 2 (page 93) of [21] also resembles the same type of specification of the two relevant physical quantities along the two axes of coordinates.

4. Examination of the Traditional Approaches Regarding Specification of Two Physical Quantities along the Two Axes of Coordinates in Drawing Graphs

Let us now consider the first approach mentioned in the last section in which the names of the two relevant physical quantities are specified along the respective axes of coordinates, as shown in Fig. 1(a), for drawing a graph. As has been stated earlier, in drawing the “Potential difference versus Electric current” graph following this approach, it is required to plot “Electric current” along X-axis and “Potential difference” along Y-axis. Now, it is to be noted that each of “Electric current” and “Potential difference” corresponds to a physical quantity. Hence, each of them must have a numerical value along with unit. So, each coordinate of a point under such a plotting should have a numerical value followed by the corresponding unit. Since the graph is drawn in a real space in which the coordinates of a point are an order pair of real numbers, such a coordinate of a point having a numerical value followed by relevant unit is totally forbidden from the concept of real space. Hence this type of approach of drawing “Potential difference versus Electric current” graph by plotting “Electric current” along X-axis and “Potential difference” along Y-axis is ambiguous. Hence the long-used concept of drawing a graph with specification of the names of two relevant physical quantities along the two axes of coordinates of a two-dimensional rectangular Cartesian coordinate system is totally ambiguous.

Following the second approach, as shown in Fig. 1(b), one is required to specify the two relevant physical quantities such as "*V,* volts" and "*I,* amp" along the X and Y axes of coordinates respectively for representing the current in a particular copper conductor as a function of potential difference. Now, it may again be noted that, here *"V"* stands for the symbolic representation of the physical quantity "potential difference", and *"I"* stands for the symbolic representation of the physical quantity "Electric current". Thus both the numerical value as well as the unit of potential difference are associated with the symbol *"V"*. In a similar manner, the numerical value as well as the unit of electric current are associated with the symbol *"I"*. So, further specification of "volts" and "amp" with the symbols *"V"* and *"I"* respectively is very much ambiguous. Such an ambiguity will never arise if there had been an incorporation of a statement in [11 -13] like the following one quoted below from page 13 of [22].

"For purposes of calculation, it is the measure of the magnitude that is of importance, and, to avoid a tedious prolixity of statement, such an expression as "a velocity V" will often be used in the sense "a velocity whose measure is V units of velocity".

On account of the aforesaid reason, the mode of approach adopted in Fig. 1 (page 4/11), Fig. 3(a), (b), (c), (d) (page 5/11), and Fig. 4(a), Fig. 4(b) (page 6/11) of [11], in Fig. 3(a) and Fig. 3(b) (page 4) of [12], and in Fig. 5 to Fig. 7 (page 6), Fig. 9, Fig. 10 (page 7) and Fig. 11, Fig. 12 (page 8) of [13] for the labeling of physical quantities along the axes of coordinates in drawing the relevant graphs could be claimed as ambiguous.

The third approach described in the previous section concerning the specification of two relevant physical quantities along the two axes of coordinates in graph drawing is found to be followed in many traditional resources. In this approach also the name of a physical quantity is followed by the specification of its corresponding unit inside a first bracket. For example, as shown in Fig. 1(c), to represent the graphical nature of variation of potential difference across a metallic conductor with the change of electric current through it, "Electric current (amp)" has been specified along X-axis along with the specification "Potential difference (volts)" along Y-axis.

But it can again be noted that, each of the "Electric current" and "Potential difference" is a physical quantity, having a numerical value along with the corresponding unit. Thus specification of "(amp)" and "(volts)" with the two physical quantities "Electric current" and "Potential difference" respectively is very much ambiguous. On account of this reason, this type of specification of two relevant physical quantities along the two axes of coordinates in graph drawing found to prevail in many traditional resources is claimed to be ambiguous.

As described in the previous section, to represent the graphical nature of variation of potential difference across a metallic conductor with the change of electric current through it, the fourth approach considers specifying "Electric current in ampere" along X-axis, and "Potential difference in volt" along Y-axis (Fig. 1(d)). As before, it may be noted that "Electric current" as well as "Potential difference" are both physical quantities. Thus, each of the "Electric current" and "Potential difference" has a numerical value along with corresponding unit. Thus the specifications "Electric current in ampere" as well as "Potential difference in volt" are very much ambiguous. Based on this fact, such type of specifications of two relevant physical quantities along the two axes of coordinates in drawing of graphs, prevailing so far in many places of the long- running literature, are being claimed to be ambiguous.

5. Ambiguous Specification of Two Physical Quantities along the Two Axes of Coordinates Leading to Misleading Procedure of Finding Slope from Graph

On account of the ambiguous procedure of specifying two relevant physical quantities along the two axes of coordinates, one is often led to develop a misleading concept regarding the coordinates of a plotted point in the graph as a consequence of which each coordinate of a plotted point in the graph is assumed to have a numerical value along with a corresponding unit. Since a graph is always drawn in real space, such a concept regarding the coordinate of a plotted point in the graph is very much wrong on account of the fact that it violates the fundamental concept of coordinate geometry according to which coordinates of a point in two-dimensional real space are an ordered pair of real numbers.

An example for this type of misleading concept is now being considered from [23]. In the solution 2.7 (d) of Example 2.7 appearing at page number 24 of [23], slope (as has been indicated in the graph shown in Fig. 2.17) has been calculated as follows.

$$\text{Slope} = v = v_0 + at =$$
$$(70\ m/s) + (6.25\ m/s^2)(5\ \text{s}) = 101.25\ \text{m/s}$$

Again in the procedure of solution of Example 2.3 (c) appearing at page 28 of [24], slope of the green line at $t = 2.5\ s$ (point ©) in Figure 2.4(a) of [24]) has been calculated as follows.

$$v_x = \frac{10\ m - (-\ 4\ m)}{3.8\ s\ -\ 1.5\ s} = +\ 6\ m/s$$

It would now be interesting to quote the following line " $\frac{\text{dT}}{\text{dt}} = \text{Tangential slope}$ " from page 19 of [25].

Furthermore, the following quoted line "$\frac{dT}{dt} = 0.0047°C/s$" also exists subsequently in the said page 19 of [25], the slope being computed by making use of the graph shown in Fig. 7a displayed in page 19 of [25].

It can now be readily seen from the above calculations of slope finding that each coordinate of the two relevant points in the relevant graph has been assumed to have a numerical value tagged with a corresponding unit, as a result of which, slope (which is exclusively a pure number without any unit for it) also appears to have a numerical value along with a unit tagged with it. Such an assumption is going against the fundamental concept regarding coordinate of a point in Coordinate geometry according to which the coordinates of a point are an ordered pair of real numbers and hence very much ambiguous and it leads to misleading procedure of slope finding.

6. Unambiguous Approach to be Adopted for Specifying Two Physical Quantities along the Two Axes of Coordinates in Graph Drawing

It would be worth mentioning here that, in the representation of data-based graphs (experimental or theoretical), the graphs are drawn in a two-dimensional plane defined by the two axes of coordinates (viz. OX and OY) in real space. Now, the coordinates of a point lying on such a plane (XY plane) in the real space is defined as an ordered pair of real numbers denoted by (x, y), where each of x and y corresponds to a real number. As can be seen from the discussion in the previous sections, the aforesaid fundamental fact has been violated in most of the cases of drawing data- based experimental or theoretical graphs and hence all such procedures of graph drawing are fundamentally flawed, having no compliance with the fundamental fact that the coordinates of each point must be an ordered pair of real numbers.

Now, we note that as per "Quantity calculus" [4,5], a physical quantity can be expressed as:

$$\text{Physical quantity} = \text{Numerical value} \times \text{Unit}$$

or,

$$\frac{\text{Physical quantity}}{\text{Unit}} = \text{Numerical value} \qquad (1)$$

This relation (1) may be employed to represent the numerical values of the two physical quantities along the two axes of coordinates instead of specifying the symbol (or name) of each of the two physical quantities or instead of specifying the numerical value of each of the two physical quantities along with its unit along the two axes of coordinates to get rid of the flaw prevailing so far in the traditional procedure of graph drawing.

For example, the more precise and unambiguous procedure to represent the graphical nature of variation of potential difference with the change of electric current in case of a conductor should consist of specifying Current/Ampere along X-axis and Potential difference/Volt along Y-axis and is shown in Fig. 1(e).

7. Conclusion

Traditional approaches of specifying two physical quantities along the two axes of coordinates in graph drawing are of concern to this paper. It has been discovered that there exists ambiguity in each of those approaches of specifying two physical quantities along the respective axes of coordinates for representing the graphical nature of variation of one of those two physical quantities with the change of the other. Consequent upon the existence of such ambiguous specification of the physical quantities along the axes of coordinates, each of the two coordinates of a point is forced to have a numerical value along with a unit tagged with it as has been reflected in the calculation of slope from a graph, thereby violating the fundamental concept of Coordinate geometry according to which the coordinates of a point are an ordered pair of real numbers.

Apart from that, none of those approaches takes proper care of the fundamental fact that a physical quantity has got a numerical value along with a corresponding unit tagged with it, or more precisely, as per "Quantity calculus" [4,5], a physical quantity can be expressed as:

$$\text{Physical quantity} = \text{Numerical value} \times \text{Unit}$$

As a result, all the traditional approaches in regard to the specification of two physical quantities along the two axes of coordinates in graph drawing stand ambiguous.

The issue raised in this paper is concerned with the ambiguous procedure of labeling physical quantities along the axes in drawing graphs, which has been prevailing so far in the long-used scientific literature. The paper also offers a solution to get rid of the aforesaid ambiguous procedure so as to bring clarity and sophistication in the relevant procedure of graphing.

The aforesaid issue raised along with the relevant solution offered are both novel and original and never considered by any one earlier.

In view of the above, the present work could not be placed into context to any other earlier works dealing with the same issue to see that it is unusual. However, it could be compared with the two other works [1,3], reported earlier by the author, in relation to graphing to judge its novelty and originality. Such a comparison has been made in Table 1 below.

Table 1. Comparative study of the present scheme with two other earlier works related to graphing by the author

Ref. No.	Title of published paper	Sum and substance of the contribution
[1]	Discovery of misleading graph titles at many places of the traditional scientific literature	An extensive literature search has been made to discover the existence of misleading titles of graphs violating the standard norm in the said context at many places of the scientific literature, following which well-defined self-explanatory graph titles as per traditional convention have been proposed to enhance quality of graphing.
[3]	Discovering the existence of flaw in the procedure of drawing enlarged experimental curve	The traditional practice of drawing graphs with maximum enlargement making use of proper scales along both the axes of coordinates has been put into context to the fundamental concept of "Enlargement" in Transformation geometry to discover that such a practice of drawing enlarged graphs using proper scales is in conflict with the fundamental concept of "Enlargement" in Transformation geometry. To get rid of such a conflict, the urgent need of using similar scales along the two axes of coordinates for drawing enlarged graphs has been emphasized.
Present paper	Discovery of ambiguity in the traditional norms of specifying physical quantities along the axes of coordinates in drawing data based graphs	By dint of an extensive search of relevant literature, it has been discovered that the traditional norms of specifying physical quantities along the axes of coordinates in graphing overlook the inherent nature of a "Physical quantity" and hence they are ambiguous. Making use of "Quantity calculus", an unambiguous solution of the aforesaid problem of labeling physical quantities along the coordinate axes in graphing has been offered.

The present work does have an educational point as well as wide impact ranging from secondary school level up to the university and research level. In order to bring precision and sophistication in the relevant field of scientific study and research as well as to enhance the relevant literature, immediate implementation of the proposed unambiguous approach in respect of labeling of physical quantities along the axes of coordinates in the procedure of graphing is essential.

Declaration of Conflict of Interest

This is to declare by the author that there are no known competing financial interests or personal relationships that could influence the work reported in this paper.

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