Episodic Conceptualisation as Genesis of Pupils' Alternative Conceptions about Graphs in Kinematics

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Abstract

In the present study, the possible episodic structures which the pupils are likely to auto-generate while being taught about graphs in kinematics, have been identified. The effects of this episodic conceptualisation on the responses of pupils of Classes X and XII, and practising higher secondary teachers to comprehend problems related to the construction and interpretation of graphs in kinematics have been investigated. We have suggested focused teaching points to be noted while teaching graphs so as to minimise the generation of alternative conceptions.

Introduction

In the last several years, motivated by Constructivism, an active research programme has been established to study pupils' alternative conceptions (hereafter referred to as ALCONs) and their implications for teaching-learning of science. Overviews as well as critical and interpretative reviews of the works in this area can be obtained from the papers of Mohapatra (1997), Driver (1995), Wandersee et al. (1993), Mohapatra (1989), Driver (1989), Hashweh (1986), Gilbert and Watts (1983), Driver and Erickson (1983), from the books by Treagust et al. (1995), Glynn and Duit (1995), Fensham et al. (1994), Driver

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et al. (1993), Osborne and Freyberg (1985), Driver et al. (1985), and from the conference proceedings (Novak 1993, 1987; Archenhold et al. 1980) during different periods. Some recent works include Agarwal (2014), Taber (2014), Mohapatra, Mahapatra and Parida (2015).

In a constructivistic framework (Glasersfeld 1995), it is now conclusively established that (a) knowledge is constructed by the cognising subject, and (b) pupil's ALCON is the single most important factor (Ausubel 1968) that determines the degree and quality of this construction. However, the full potential of the findings and conclusions of the research studies about pupils' ALCONs in helping the classroom teachers to improve or modify their teaching strategies so that pupils construct their knowledge in the form in which they are expected to construct, is yet to be realised in our country though suggestions have been offered, for example, in the National Curriculum Framework 2005 (NCERT 2005). Such attempts seem to have achieved partial success elsewhere (see Palmer 2005; Wenning 2008).

We argue that the individualism in the form and structure of pupils' ALCONs about specific concepts is one of the major hindrances for taking the research findings and teaching models into the classroom. Within the classroom, a teacher can hardly afford the luxury of simultaneously handling a number of different ALCONs of a group of pupils about a single concept. However, a group of pupils having the same or similar ALCONs can possibly be exposed to a single, well planned treatment for effective modification of the ALCONs. But associated with this is the issue that a treatment will be as good as the diagnosis of the genesis of the ALCONs. Hence, to diagnose the genesis process that is likely to lead a group of pupils to common ALCONs could possibly be the first step towards functionally taking the research findings about ALCONs vis-à-vis constructivism into the classroom.

There have been attempts to identify the possible origins of pupils' ALCONs on the basis of field-based studies (see Mohapatra 1988). Based on the findings, the genesis has been classified into the following three categories.

Induced Incorrect Generalisation (IIG)

Due to repeated reinforcement of the validity of a concept in a limited zone of the domain of its validity, there is a high possibility that pupils will auto generate (through self construction) a generalisation which is incorrect (Mohapatra and Bhattacharya 1989). Five discrete processes through which IIG operates, at least in the concept domains investigated in the above studies, have also been located (Mohapatra 1988a). They are—

- the process of 'conceptual reversibility'

- the process of ‘conceptual continuity’
- the process of ‘conceptual extrapolation’
- the process of ‘conceptual myopia’
- the process of ‘conceptual incongruity’

Connotative Relativity

A label, specifying a concept, may convey a meaning to the pupils which is different from what the teacher desires to convey through the transaction of formal science (see Barman and Mayer, 1994; Mohapatra and Das 1996). This leads to a state of connotative relativity.

Episodic Conceptualisation (Epi-Con)

It is observed that in many cases, the chapters in textbooks are written and arranged like independent episodes. We use the term ‘episode’ in the conventional sense of distinctive incident or occurrence. Even the classroom teaching follows an episodic pattern of presentation as very often, the teachers say, for example, we have completed ‘Optics’, next we go over to ‘Electricity’. It is argued (Mohapatra 1990, online 2007; Arora et al. 2010) that such an episodic nature of presentation of different units and sub-units is likely to induce the pupils to develop isolated, unconnected islands of equilibration. Three discrete processes through which ALCONs manifest due to Epi-Con, at least in the concept domain investigated (Mohapatra 1990, online 2007) have also been located. They are—

- the process of ‘non-use’ of an episode
- the process of ‘misuse’ of an episode
- the process of right use of wrong episodes

The Questions

In the present study on episodic conceptualisation, we attempt to seek answers to two questions.

1. In the context of graphs, what are the possible episodes the pupils might have internalised?
2. What are the likely effects of these episodes, in so far as generating ALCONs in the concept domain of graphs in kinematics is concerned?

Relevant Literature

Graph (also called a chart), as a symbolic diagram or pictorial representation of the relationship between two or more variables, has widespread application in many different domains. A large number of the Internet-based resources on the use of graphing in teaching learning are available (for example, www.csulb.edu/~thenrique/Run.pdf for middle and high school students; www.mathgoodies.com/lessons/toc_vol11.html for data and graphs; www.teach-nology.com> Free Teacher Worksheets > Math; www.teach-nology.com >Teacher Resource> Lesson Plan

Center> Math; www.inspiration.com/visual-learning/plots-and-graphs). In India, the National Curriculum Framework 2005 (NCERT 2005) stipulates that pupils ought to learn graphical technique in mathematics in the early years of schooling, so that they can appreciate relationships between quantities, not in mathematics alone but in science and other areas also (NCERT 2005, p. 44). This is reflected in the Learning Outcomes relevant to Class VII (Mathematics) and Class VIII (Mathematics), recently designed by the National Council of Educational Research and Training (NCERT 2017).

In the secondary level school science, graphs are used to teach concepts in kinematics—a branch of science that deals with motion of bodies. Graphs also help the students to derive kinematical equations for different kinds of motion such as, motion with uniform velocity, motion with uniform acceleration, etc. It was but natural that researchers divert their attention to diagnose and map pupils' ALCONs about graphs in kinematics.

Most of the studies have aimed at assessing pupils' abilities in constructing and interpreting graphs. One of the earliest attempts in this regard was by Trowbridge and McDermott (1980), wherein they hit upon the potentially rich area of pupils' misinterpretation of 'velocity' as 'displacement/time' and not as 'change in displacement/change of time'. Saltiel and Malgrange (1980) concluded from their study that graphical representations can easily be misleading—decomposition of a velocity vector (pertaining to a unique frame) into its components (vertical and horizontal, or radial and tangential) leads to a figure which may be easily confused with a velocity composition diagram illustrating the change in velocity from one frame to another. Shaw et al. (1983) made a longitudinal study of the graphing ability of students in grades VII through XII. McDermott (1984) opined that because many relationships, implicitly assumed by teachers, are not obvious to students, and teachers need to help students make explicit connections among physical concepts, their mathematical representations like graphs and the physical world are beset with difficulties. McKenzie and Padilla (1986) investigated the problems associated with graphing skills in science. McDermott et al. (1987) identified some common errors exhibited by students in interpreting graphs in kinematics. They observed that the errors are not idiosyncratic but cut across students belonging to different populations and different levels of sophistication. Brasell (1987) studied the effect of real time laboratory graphing on learning graphic representations of distance and velocity. Continuing in the same line, Berg and Phillips (1994) investigated the relationship between logical thinking structures and the ability to construct and interpret graphs. They were able to classify pupils' responses in to three types—'right answers/right reasons', 'right answers/wrong reasons', and answer scored 'wrong' but correct for 'valid reasons', in the context of students' abilities to construct and interpret line graphs. Recently, a study examined the use of graphs by teachers as a part of professional development (Bautista et al., 2015).

In the Indian context, a mention may be made of a study conducted in 1997 in which 500 valued answer scripts of Class XII physics pertaining to the 1995 Annual Examination of the Council of Higher Secondary Education, Odisha were examined by a group of experts to unearth common errors committed by students in answering the paper. The findings related to the graphs states that students have a poor perception of graphs in general, including nature of the graph expected, procedure for plotting the graph, interpreting it, and extracting information from it (Parida 1998).

Episodes in the Teaching of Graphs

In a Brunerian framework, the essential attributes of a graph are its slope and its intercept on any axis, whereas the non-essential attributes are the coordinates of a point on the graph and the scales. However, the essential attributes of a straight line graph are global in nature in the sense that at every point, the slope is the same and there is a fixed intercept on an axis, as for example, the straight line given by the equation $y = m x + c$, where 'x' is the independent variable, 'y' is the dependent variable, and 'm' and 'c' are constants denoting the slope and intercept, respectively. But the essential attributes of any other curve are local in nature because the slope may vary from point to point and/or a curve may have several intercepts on an axis.

Keeping the above framework in mind, the textbooks and curricula of various classes were analysed and actual classroom teaching was also observed. It was seen that pupils are taught and instructed to use graphs in various contexts over a period of four years comprising Classes VII, VIII, IX and X and reinforced during the two years of higher secondary or +2 stage. The contexts and the associated expected learning outcomes may be described in the teaching activities as follows.

T1 How to draw a graph

This is discussed in the secondary classes in mathematics and science. Pupils are given a set of points and asked to represent the same by a graph. The activity enables the learners to appreciate the important aspects, such as the relationship between two quantities, deciding which of the two is an independent quantity and which one is dependent, identifying and drawing coordinate axes, choosing appropriate scales, plotting of points and marking of their positions on the graph.

T2 Given a set of points, how to draw a graph that possibly describes the situation best

The pupils are exposed to this while doing practicals in the secondary and higher secondary classes, where they are to plot the observations taken by them and draw the graph that describes the observations best, when, for example, the graph does not pass through all the data points.

T3 How to calculate the slope of a straight line graph

This is usually practised by the pupils at the higher secondary stage, where for example, (a) they compute the value of acceleration due to gravity by plotting L-T^2 graph (L denoting the length of a simple pendulum and T, the time period of oscillation of the same) and finding its slope, or, (b) obtaining the resistance of a conductor from the slope of V–I graph (V being the potential difference across the conductor and I, the current flowing through it).

T4 How to find the value and significance of the intercept of a graph with any of the axes

This may for instance be illustrated in the context of 1/u – 1/v graph for reflection of light by a spherical mirror (u and v being the object distance and image distance, respectively), a task for higher secondary students.

T5 Extrapolation and interpolation of graphs

Graphical extrapolation is a good way to determine, for example, the focal length of a convex lens from the 1/u – 1/v graph referred to above. As an illustration of interpolation, students are asked to find the length of a second's pendulum from the relevant L-T^2 graph. Such exercises are usually assigned to the higher secondary students.

T6 Pictorial representation of theoretical formula

Pictorial representation of a theoretical formula through graph often leads to a better perception and better appreciation of the relationship between physical quantities. Pupils at the higher secondary stage are initiated into this by graphically showing how displacement, velocity, and acceleration of a body executing simple harmonic motion, change with time.

T7 Obtaining equations from graphs

At the secondary and higher secondary levels, pupils are introduced to the displacement-time and velocity-time graphs for bodies moving with uniform velocity or uniform acceleration.

The graphs are then used to establish the kinematical equations.

If one analyses the above teaching activities and the consequent learning experiences of the pupils, one can discern the following episodes or sub-episodes in operation—

E1 Episodes which consider the non-essential attributes as essential attributes. This is so because due to T1, T2 and partly T3, there is a reinforcement to put emphasis on the non-essential attributes, like the coordinates of points, choice of scale to draw the graph. Thus, a distorted episode construed from faulty teaching structures is likely to get imprinted in the minds of the pupils.

E2 T4 and T5 may be grouped together as an episode, as in these the pupils learn how to find out the value of one coordinate when the other is given. It may be noted that in this episode again, the non-essential attributes are unintentionally emphasised by intentionally designed applications.

E3 T6 is itself treated as an episode. Since the shape of the graph has similarity with the actual shape of, say, a wave in the real world, the pupils may develop the cognition that shape of the graph is the shape of the path taken by the particle during its motion.

E4 T3 and T7 may be combined together as T7 also involves the calculation of slope. In this case, from the observation of classroom teaching, it was seen that the pupils are guided to see the beauty and ease of derivation of the kinematical equations, and the physics involved in the graphs are rarely emphasised. Graphs other than those given in the textbooks, and depicting novel physical motions, are rarely discussed.

E5 During T7, the difference between (a) velocity and speed, (b) instantaneous velocity (from the slope as in T3 and T7, and average velocity, (c) displacement and distance are hardly discussed in the context of graphs. As a consequence, the distinction between the members of each pair is obliterated in the minds of the pupils, thereby leading to an episode where each pair of concepts is treated as a synonymous pair.

The Method Adopted in the Investigation

The method adopted in the present study comprises the following components.

The tool

It was felt that the tool should have such items which would try to identify the effects of the Epi-Cons on pupils' comprehension and ALCONs as regards

1. the construction of graphs, and
2. the interpretation of graphs

In the above framework, it was noted that graphs in kinematics are taught in the secondary classes to

1. explain the nature of the graphs between kinematical variables under various conditions of linear motion.
2. derive kinematical equations for linear motion under uniform acceleration.

The graphs are then discussed again in conjunction with calculus at the higher secondary stage to derive the same equations. However, as stated earlier, the pupils are also exposed to graphs in the units on thermodynamics, waves, oscillations, optics, and electricity and magnetism. This is likely to produce latent effects on the pupils' comprehension about graphs in kinematics.

The tool used is described below in the form of 13 questions—

Q.1 Look at the velocity-time (v-t) graph (Figure 1) of a body and answer the following questions.

(a) Does it describe the motion of a body? Yes/No

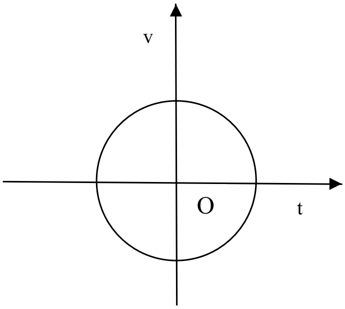

Figure 1

(b) If your answer is YES, then describe in one sentence the type of motion the body is executing.

Q.2 Look at the distance travelled-time (d-t) graph (Figure 2) of a body and answer the following questions.

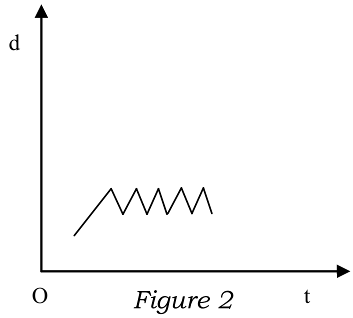

Figure 2

(a) Does it describe the motion of a body? Yes/No

(b) If your answer is YES, then describe in one sentence the type of motion the body is executing.

Q.3 Look at the displacement-time (s-t) graph (Figure 3) describing the motion of a body. What is the shape of the path traversed by the body?

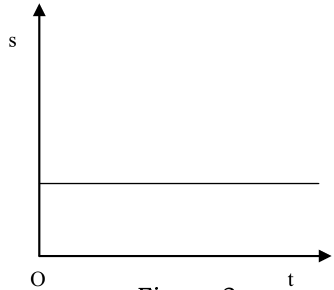

Figure 3

Q.4 Look at the displacement-time (s-t) graph (Figure 4) describing the motion of a body. What is the shape of the path traversed by the body?

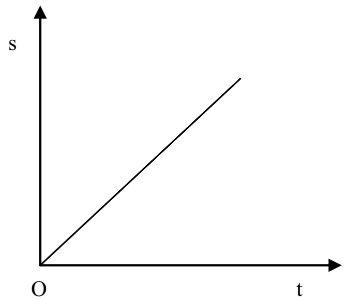

Figure 4

Q.5 Draw the velocity-time graph for a body moving with uniform velocity.

Q.6 Draw the velocity-time graph for a body at rest.

Q.7 Figure 5 shows the displacement-time (s-t) graph of a moving body. At which of the lettered point/points on the graph,

(a) is the body at rest? Explain your answer in two sentences.

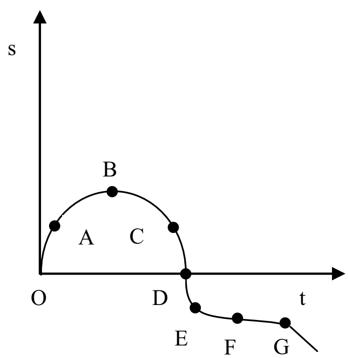

Figure 5

(b) does the body have maximum velocity? Explain your answer in two sentences.

(c) is the body turning around? Explain your answer in two sentences.

Q.8 Figure 6 shows the displacement-time (s-t) graphs for two bodies, A and B, moving along the same straight line. The unit of time is denoted by sec.

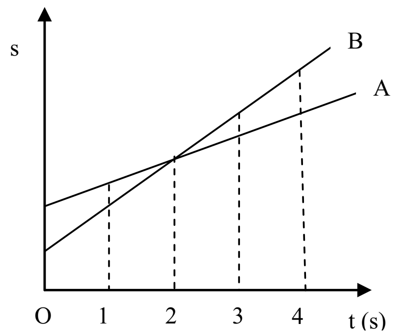

Figure 6

(a) At t = 1 sec, is the speed of A greater than, less then, or equal to that of B? Explain your reasoning.

(b) Do the two bodies, A and B, ever have the same speed? Yes/No

If your answer is YES, state at what time their speeds are equal. Explain your reasoning.

(c) At t = 4 sec, is the speed of A greater than, less than, or equal to that of B? Explain your reasoning.

Q.9 Figure 7 shows the displacement -time (s-t) graph of an oscillating simple pendulum. At which of the lettered point/ points on the graph

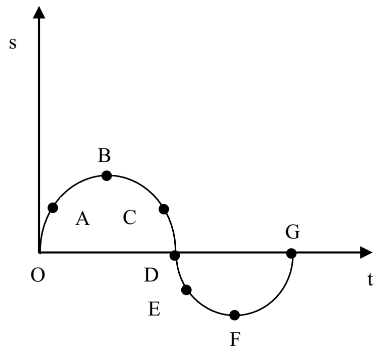

Figure 7

(a) is the pendulum at rest?

(b) is the pendulum speeding up?

(c) is the pendulum turning around?

(d) is the pendulum slowing down?

Q.10 A body was at rest at the position of 3m (marked A in Figure 8) from the origin O at time t = 0. Then it moved with a constant velocity for 1 second. At the end of 1 second, it remained at rest for 2 seconds. Then it came back to the starting point, A, in 2 seconds with a constant velocity. Draw in Figure 8 the displacement-time (s-t) graph depicting the motion of the body.

Q.11 In the above case, draw in Figure 9 the velocity-time (v-t) graph for the motion of the body.

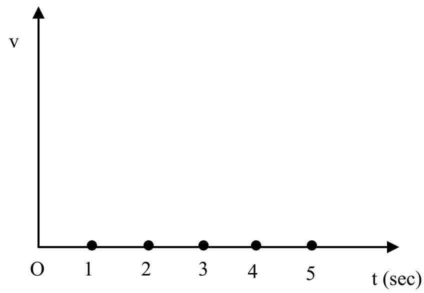

Figure 9

Q.12 A rubber ball is released from a height h. It takes 2 seconds to reach a marble platform. Then it rebounds and reaches the same height in 2 seconds. Draw the velocity-time (v-t) graph in Figure 10 for the

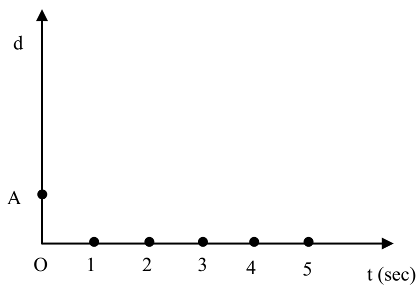

Figure 8

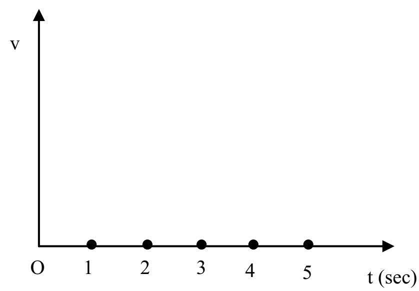

Figure 10

motion of the ball, taking the upward direction as positive.

Q.13 Figure 11 shows the velocity-time (v-t) graphs for two bodies, A and B, which are moving along the same straight line after starting from the same point.

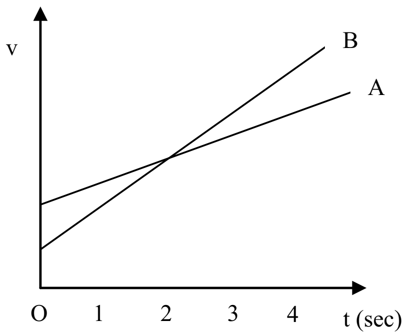

Figure 11

(a) At t=1 sec, is the acceleration of A more than, less than, or equal to that of B?

(b) Do the two bodies, A and B, ever have the same acceleration? Yes/No

If your answer is YES, state at what time their accelerations are equal.

We need to point out that Figures 5 and 6 of the tool are taken from the work of McDermott et al. (1987), although the questions, that are asked, are not exactly the same. Also, some of the diagrams may be found in the Physics Textbook for Class XI Part I (NCERT 2014). For example, Figure 1 of the tool appears as Figure (b) in Exercise 3.16 on page 57 of the textbook and Figures 3, 4 and 6 of the tool appear as Figure 3.2(a) on page 41, Figure 3.2(b) on page 41 and Figure 3.17 on page 52 respectively though in the textbook the graphs correspond to position-time (x-t) rather than displacement-time (s-t), as in the present case.

The Subjects

Table 1 summarises the subjects involved in the study. Keeping in view the fact that graphs in kinematics are taught in the secondary and again in the higher secondary (+2) classes, the pupil subjects were taken from Classes X and XII. 36 postgraduate teachers (PGTs) teaching physics to the higher secondary pupils in Kendriya Vidyalayas (KVs) and Jawahar Navodaya Vidyalayas (JNVs) who attended an orientation workshop conducted at the Regional Institute of Education, Bhubaneswar were also used as subjects. As may be seen from Table 1, we selected students from both English and Odia medium schools to discover differences, if any, arising out of linguistic considerations.

Administration of the Tool

In a trial administration, it was observed that the pupils of Class X took about 40 minutes to answer the 13 questions. However, lest the shortage of time for completing the tool items might force some pupils to give hasty responses resulting in

Table 1
Break-up of Sample Selected for the Study

Type of Subject	Details	Number
Pupils	Odia Medium Schools	
P1	Class X (age group 15–16 years), Capital High School, Unit III, Bhubaneswar	72
	Class X (age group 15–16 years), Govt. Girls High School, Unit IX, Bhubaneswar	51
	Class X (age group 15–16 years), B.M. High School, Old Town, Bhubaneswar	66
	Total	**189**
P2	English Medium Schools	
	Class X (age group 15–16 years), Govt. Boys Senior Secondary School, Port Blair, A & N Islands	56
	Class X (age group 15–16 years), D.M. School, Bhubaneswar	42
	Class X (age group 15–16 years), KV1, Bhubaneswar	36
	Total	**134**
P3	Colleges (+2 Wings)	
	+2 2nd year (age group 17–18 years), B.J.B. College, Bhubaneswar	116
	+2 2nd year (age group 17–18 years), R.D. Women's College, Bhubaneswar	98
	+2 2nd year (age group 17–18 years), Rajdhani College, Bhubaneswar	107
	Total	**321**
Teachers		
T1	PGT, KVs	27
	PGT, JNVs	9
	Total	**36**

noises, it was decided to allow a time of one hour to both Classes X and XII second students to complete the test. Teachers were also given the same amount of time for test completion.

Results and Discussion

The teachers expressed the view that they were being exposed to such a type of test for the first time in their career. This lack of experience was a bonus for the investigators because in the above circumstances, the teachers had to fall back upon their comprehension and not rote memory to answer the questions, thus opening up greater probability of their ALCONs getting reflected in their responses. The pupils, on the other hand, definitely enjoyed answering the questions. On the completion of the test, a few pupils as well as teachers were engaged in group discussions so as to have indicators of their thought process.

An analysis of the test-cum-answer sheets showed that the pupils as well as teachers gave discernible ALCONs or simple combinations of them against each question, as detailed below. The asterisked responses are the correct ones. The responses are indicated by the symbol R, followed by the question number.

In case of Question 1 (Q. 1), the responses were as follows.

R.1(a).1: *No (correct use of E5)

R.1(a).2: Yes (misuse of E3 and E5)

R.1(b).1: Circular motion (misuse of E3)

R.1(b).2: Simple harmonic motion (misuse of E3). In the class, simple harmonic motion is taught by using the motion of a particle on the circle of reference and analysing its displacement projected on any diameter of the circle.

In case of Question 2 (Q.2), the responses were as follows.

R.2(a).1: *NO (correct use of E5)

R.2(a).2: YES (misuse of E3 and E5)

R.2(b).1: Zigzag motion (misuse of E3)

R.2(b).2 : Simple harmonic motion (misuse of E3). A response like 'to and fro motion' has been clubbed with R.2(b).2.

In case of Question 3 (Q.3), the responses were as follows.

R.3.1: *The body is at rest (correct use of E1 and E4)

R.3.2: Straight line path (misuse of E3 and even E5, non-use of E1)

In case of Question 4 (Q.4), the responses were as follows.

R.4.1: *It is a straight line path (correct use of E1 and E4)

R.4.2: Straight line path from one corner to another corner (misuse of E3 and non-use of E1)

R.4.3: Shape of path cannot be known (non-use of E1 and E3)

In case of Question 5 (Q.5), the responses were in the form of graphs as specified below.

R.5.1: *A straight line parallel to t-axis (correct use of E1 and E3)

R.5.2: A straight line inclined to t-axis with a positive slope (misuse of E1 and E5 and non-use of E4)

R.5.3: A straight line inclined to t-axis with a negative slope (misuse of E1 and E5 and non-use of E4)

At this point, it is worthwhile to record the discussion that ensued with a pupil opting for the response R.5.2.

Interviewer: (showing the graph drawn by the pupil) In this case, you have drawn a straight line graph inclined to t-axis.

Pupil: Yes, sir.

Interviewer: Why this shape of the graph?

Pupil: It has to be so.

Interviewer: Why has it to be so?

Pupil: Because...

Interviewer: (coaxing) Yes, because...

Pupil: Sir, because, you see, in this case the distance of the body from the origin will go on increasing.#

Interviewer: Yes, so...

Pupil: So, the graph has to be as I have drawn.#

The responses marked with # clearly show an utter confusion and chaos in the application of the episodes. The pupil confuses between the distance travelled and the velocity. This is an outcome of the misuse of E1. Then, in his mind, he has supportive flashes of such a graph (of course between displacement and time and not between velocity and time when the body is moving with uniform velocity) studied in kinematics. But, it seems he has forgotten the essential attributes of the graph, like the variables.

In case of Question 6 (Q.6), the responses were in the form of graphs as specified below.

R.6.1: *The t-axis itself (correct use of E1 and E4)

R.6.2: The v-axis itself (misuse of E1 and E4)

R.6.3: A straight line parallel to t-axis (misuse of E1 and E3)

In case of Question 7 (Q.7), the responses were as follows.

R.7(a).1: *B and F (correct use of E1 and E4)

R.7(a).2: O and D (misuse of E1 and E4)

R.7(b).1: *O (correct use of E4)

R.7(b).2: B and G (misuse of E1 and E4). Responses like 'only B' are clubbed under R.7(b).2.

R.7(c).1: *B (correct use of E1 and E4)

R.7(c).2: D (misuse of E1 and E4)

At this point, we record the conversation that took place (in respect of response R.7(a).2) with one of the pupils as a part of the structured interview, once the test was completed.

Interviewer: In this displacement-time graph of Fig. 5 describing the motion of a body, you have answered that the body is at rest at the points O and D.

Pupil: Yes, sir.

Interviewer: Why did you feel so?

Pupil: It has to be so, it is obvious.

Interviewer: Will you please explain?

Pupil: (smiles) Sir, at these two points the displacement of the body is zero and velocity is zero.$

The reply marked with $ is a reflection of episode E1. Because of the emphasis on the non-essential attributes of the graph, i.e., coordinates of points, the concept of velocity has been internalised by the pupils as displacement/time and not as change in displacement/change in time. This form of internalisation is also reflected in the responses R.7(b).2 where the pupils feel that the larger the displacement, the larger is the velocity and R.7(c).2, where the pupils express that negative displacement means negative velocity, so the turning around at D.

Manifestations of similar conceptualisations generated out of treating coordinates of points as essential attributes are also indicated in the responses to Question 8 as given below.

R.8(a).1: *Speed of A less than that of B (correct use of E1 and E4)

R.8(a).2: Speed of A greater than that of B (misuse of E1 and E4)

R.8(b).1: *No (correct use of E1 and E4)

R.8(b).2: Yes, at 2 seconds (misuse of E1 and E4)

R.8(c).1: *Speed of A less than that of B (correct use of E1 and E4/misuse of E1 and E4)

Responses R.8(a).2 and R.8(b).2 corroborate our earlier conclusions. However, response R.8(c).1 needs some discussion.

Of course, if one applies the correct use of E1 and E4 and calculates the slope of the graph, one arrives at the correct response R.8(c).1. But, peculiarly, wrong use of E1 and E4 also helps to arrive at the right answer, as is transparent from the following interview.

Interviewer: In respect of Q. 8(c) and Figure 6, you have answered that at t = 4 seconds, the speed of B is greater than that of A.

Pupil: Yes, sir.

Interviewer: Why do you feel so?

Pupil: Sir, that is what we have been taught.

Interviewer: What have you been taught?

Pupil: Sir, speed is distance divided by time, particularly, in the case of linear motion.@

Interviewer: So?

Pupil: Sir, you can see from the graph; the distance travelled by B is more than that by A at 4 sec.@@

The response marked with @ and the conclusion marked with @@ drawn from it, indicate our assertion that a wrong use of E1 and E4 has resulted in the right answer. The situation is similar to 'right answers/ wrong reasons' of Berg and Phillips (1994). It is for this reason that both the correct use of E1 and E4 and misuse of E1 and E4 have been shown as the generative causes in R.8(c).1. Perhaps only due to this, there was no variation in the response to Q.8(c). The non-existence of any other response to Q.8(c) is perhaps the strongest evidence of our presumption that Epi-Cons are one of the possible geneses of manifest ALCONs.

In case of Question 9 (Q.9), the responses were—

R.9(a).1: *B and F (correct use of E1 and E4)

R.9(a).2: O, D and G (misuse of E1 and E4)

R.9(b).1: *C (correct use of E1 and E4)

R.9(b).2: B and F (misuse of E1 and E4)

R.9(c).1: *B and F (correct use of E1 and E4)

R.9(c).2: D (misuse of E1 and E4)

R.9(d).1: *A and E (correct use of E1 and E4)

R.9(d).2: C and D (misuse of E1 and E4). Here, there were various combinations of answers like C and D, only C, only D, etc. We have clubbed them together, as the basis of these was that displacement is decreasing.

In case of Question 10 (Q.10), some of the typical responses obtained are as shown in Figure 12.

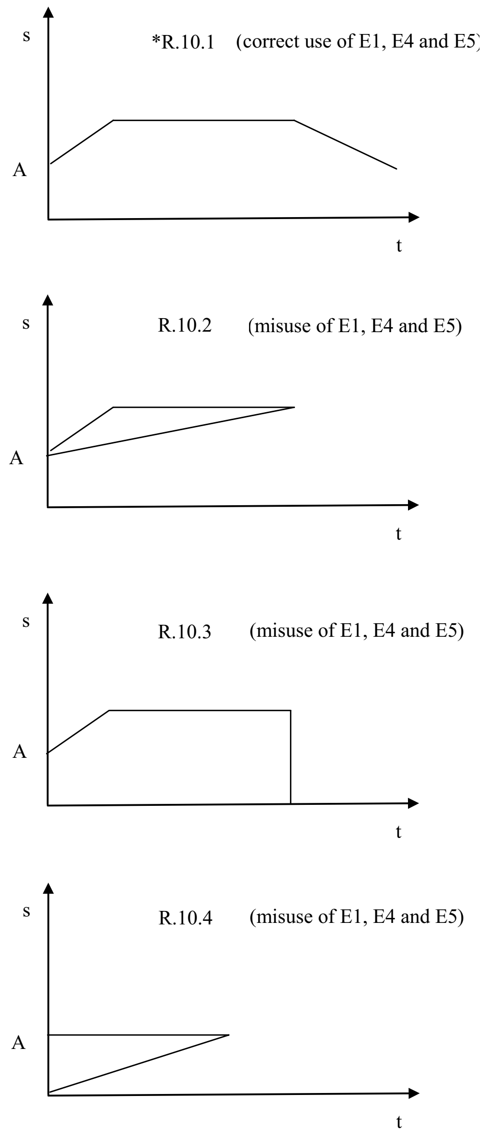

Figure 12

In case of Question 11 (Q.11), some of the typical responses obtained are as shown in Figure 13.

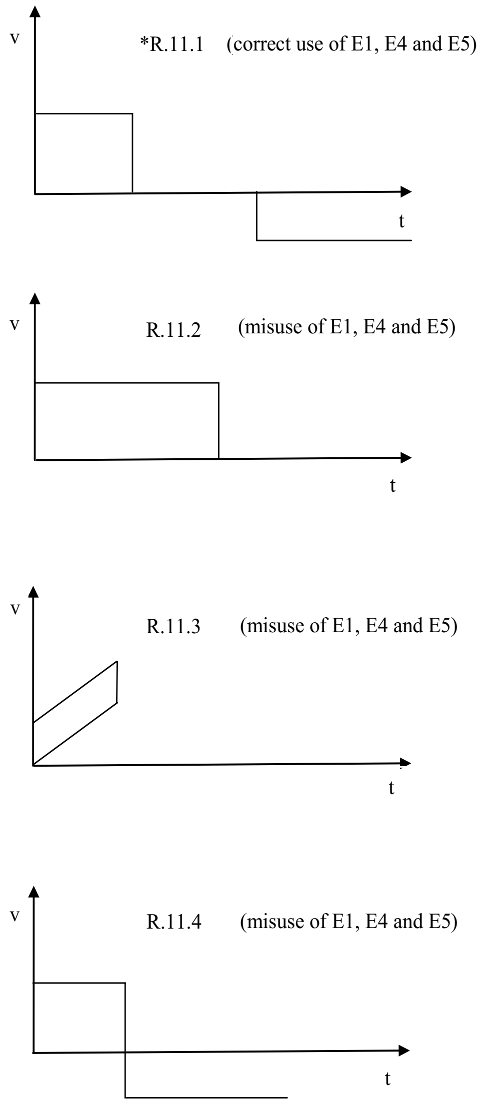

Figure 13

In case of Question 12 (Q.12), some of the typical responses obtained are as shown in Figure 14.

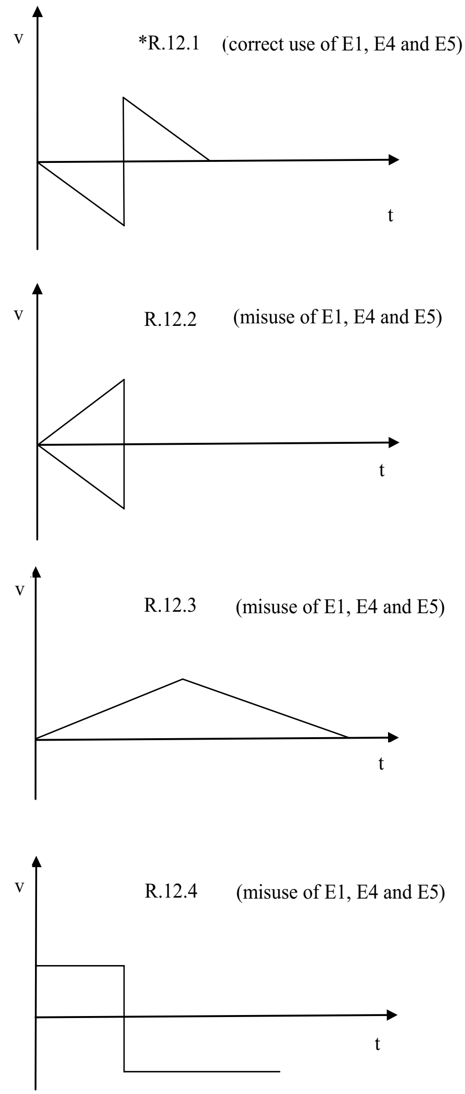

Figure 14

In case of Question 13 (Q.13), the responses were as follows.

R.13(a).1:*Acceleration of A is less than that of B (correct use of E1 and E4)

R.13(a).2:Acceleration of A is more than that of B (misuse of E1 and E4)

R.13(b).1:*NO (correct use of E1 and E4)

R.13(b).2:YES at two seconds (misuse of E1 and E4)

Responses to Q.13 are repetitions of the pattern of responses to Q.8 which has structures similar to those of Q.13, and obviously reconfirms the existence of the type of Epi-Cons and hence, the genesis.

The percentage of each group of subjects preferring any particular response in respect of any specific question is presented in Table 2 in which the correct responses are indicated by asterisk marks.

Table 2
Percentage of Subjects Preferring a Response

Question No.	Responses	Subjects			
		P1	P2	P3	T1
1(a)	*R.1(a).1	2.6	2.9	3.7	33.3
	R.1(a).2	97.4	97.1	96.3	66.7
1(b)	R.1(b).1	51.8	50.9	49.8	44.5
	R.1(b).2	45.6	46.2	46.6	22.2
2(a)	*R.2(a).1	3.1	2.2	4.0	30.5
	R.2(a).2	96.9	97.8	96.0	69.5
2(b)	R.2(b).1	77.6	82.1	70.1	52.7
	R.2(b).2	19.3	15.7	25.9	16.8
3	*R.3.1	34.4	44.1	50.2	88.8
	R.3.2	65.6	55.9	49.8	11.2
4	*R.4.1	26.5	27.7	42.6	72.3
	R.4.2	71.4	68.6	55.9	27.7
	R.4.3	2.1	3.7	1.5	0.0
5	*R.5.1	51.8	52.2	70.1	94.4
	R.5.2	45.6	43.2	25.9	5.6
	R.5.3	2.6	4.6	4.0	0.0
6	*R.6.1	9.5	11.2	26.8	88.8
	R.6.2	2.6	2.9	3.1	0.0
	R.6.3	87.9	85.9	70.1	11.2
7(a)	*R.7(a).1	6.9	9.7	30.3	61.1

	R.7(a).2	93.1	90.3	69.7	38.9
7(b)	*R.7(b).1	16.4	15.7	31.5	66.7
	R.7(b).2	83.6	84.3	68.5	33.3
7(c)	*R.7(c).1	15.4	15.0	44.6	69.5
	R.7(c).2	84.6	85.0	55.4	30.5
8(a)	*R.8(a).1	6.9	9.7	20.3	69.5
	R.8(a).2	93.1	90.3	79.7	30.5
8(b)	*R.8(b).1	8.5	13.5	26.5	77.8
	R.8(b).2	91.5	86.5	73.5	22.2
8(c)	*R.8(c).1	95.2	95.5	98.4	100.0
9(a)	*R.9(a).1	84.6	85.8	86.3	97.2
	R.9(a).2	15.4	14.2	13.7	2.8
9(b)	*R.9(b).1	55.8	56.0	62.7	77.7
	R.9(b).2	44.2	44.0	37.3	22.3
9(c)	*R.9(c).1	22.4	30.6	37.1	66.7
	*R.9(c).2	77.6	69.4	62.9	33.3
9(d)	*R.9(d).1	28.6	23.8	40.2	75.0
	*R.9(d).2	71.4	76.1	59.8	25.0
10	*R.10.1	15.8	18.1	14.4	58.4
	R.10.2	63.5	61.2	55.9	25.0
	R.10.3	10.5	10.4	14.9	11.1
	R.10.4	9.5	8.9	13.0	0.0
11	*R.11.1	23.8	32.4	25.9	50.1
	R.11.2	44.2	42.5	48.3	22.2
	R.11.3	20.0	13.3	13.4	11.1
	R.11.4	10.5	8.9	11.2	11.1
12	*R.12.1	10.9	18.0	14.7	35.8
	R.12.2	12.0	8.9	9.3	11.1
	R.12.3	63.5	61.2	59.8	41.6
	R.12.4	12.6	10.4	13.7	8.8
13(a)	*R.13(a).1	9.5	11.2	19.1	72.2
	R.13(a).2	90.5	88.8	80.9	27.8
13(b)	*R.13(b).1	10.0	10.6	22.8	75.1
	R.13(b).2	90.0	89.4	77.2	24.9

** (asterisk) indicates the correct response*

From the data in Table 2, Figure 15 is drawn depicting the percentage of each group of subjects giving question-wise correct response.

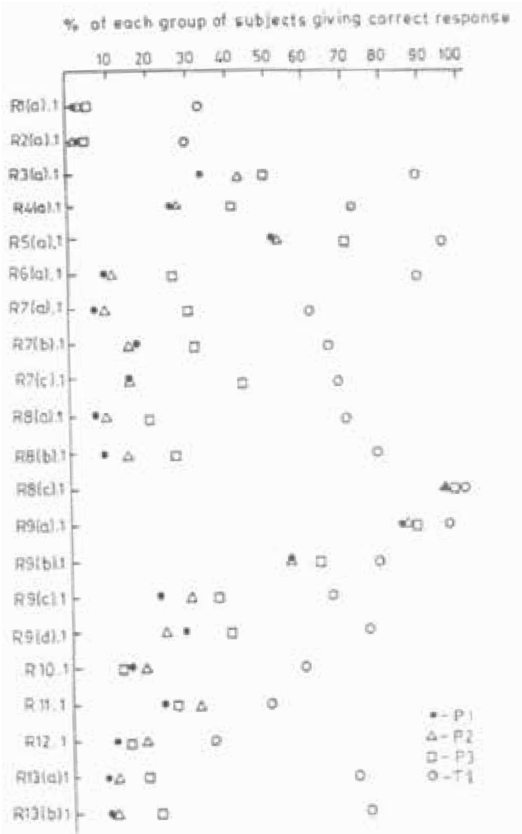

Figure 15

As discussed in the beginning, the data may be analysed from two points of view—(a) effect of Epi-Con on the ability of construct graphs, and (b) effect of Epi-Con on the ability to interpret graphs in kinematics.

Ability to Construct Graphs

There were 5 questions, Q.5, Q.6, Q.10, Q.11, and Q.12 to test this. The relatively high percentage of pupils opting for a straight line with a positive slope with t-axis in response to Q.5 shows a state of confusion between and/or overlapping of conceptualisation of v-t and s-t graphs. This confusion is also corroborated by the high percentage of pupils opting for the response R.6.3. The genesis of this ALCON does not change much with years. It is interesting to note that even higher secondary teachers are susceptible to the effect of this Epi-Con.

The graphs drawn in response to Q.11 and Q.12 show a different phenomenon, that is, they demonstrate that the subjects' thought process is dominated by the ALCON that graphs are the actual paths taken by bodies in motion. This picture has perhaps been generated by the episodes on Simple Harmonic Motion (hereafter SHM) waves, and circular motion. As a result, when the question says that finally the body comes back to the starting point, the pupils immediately picturise that the s-t and v-t graphs must also make a loop and come back to the starting point of the graph. This is manifested in a high percentage of pupils giving responses R.10.2 and R.11.3. Even the PGTs are affected by this Epi-Con.

It is felt necessary to analyse the responses to Q.12 separately. The question, of course, was a bit difficult to graphically conceptualise and answer. However, the responses are also indicative of many effects of the Epi-Cons. The high percentage of pupils as well as teachers opting for the response R.12.3 indicates a few things. Firstly, the subjects seem to have forgotten that velocity is a vector and positive direction has been specified in the question. Secondly, there seems to be a confusion between speed and velocity, as is indicated by the following discussion with one of the teachers who opted for the response R.12.3.

Interviewer: (showing the graph drawn) You have drawn this graph.

Teacher: Yes, sir.

Interviewer: As you see, the graph has two parts. Let us analyse the first part. Why do you think the graph has to be like this at the beginning?

Teacher: Sir, as the ball falls freely, its velocity increases with a constant acceleration.+

Interviewer: What about the second part?

Teacher: After the rebound the velocity of the ball decreases constantly.+

Interviewer: But as you see, the question has instructed to take the upward direction as positive.

Teacher: Yes, sir, it is negative when the ball is going up after the rebound. But, it was positive when the ball was falling freely.+

Interviewer: If you take the upward direction as positive, then when the ball was falling its velocity was becoming more and more negative.

Teacher: No, sir. How can you say that? The velocity of a freely falling body increases, it does not decrease.+

The responses marked with + clearly show the effect of the Epi-Cons. Even treating (wrongly) the graph as the actual path is evident from the response R.12.2.

Ability to Interpret Graphs

We analyse this from two angles.

Interpretation involving nature of the path and shape of the graph

Two graphs are given in Q.1 and Q.2 and the subjects are asked to describe the type of motion, if their answer is YES to the first part of the question. Again, the answers show an association of these graphs with their episodes on circular motion and S.H.M., particularly in the case of the graph in Q.2, the pupils interpreted the graph as the actual path taken by the body. As a result of this, in both the questions, about 90 per cent opted for the answer YES when the correct answer is NO. Interestingly, about 65 per cent of the PGTs also committed the same mistake.

When we come to the second part of Q.1, since the pupils are exposed to such a graph in circular motion and also SHM, almost equal percentage of pupils opt for each of the answers. Even the responses of the teachers are not much different, which demonstrates the effect of episodic nature of teaching, both on pupils and teachers. In respect of Q.2(b), since the graph has a zigzag shape, a large percentage of pupils as well as teachers opt for response R.2(b).1.

Association of the shape of graph with the actual path taken by the body is again exemplified in the high percentage of the pupils opting for response R.3.2 and R.4.2. Even about 20 per cent of the teachers have favoured these responses.

Interpretation involving slope of the graph

Under this category, it is worthwhile to compare the responses to Q.7 and Q.9. The teachers and pupils are familiar with the graph in Q.9 and perhaps not familiar with that in Q.7. The effect of this familiarity with an episode is immediately transparent from the percentage of pupils opting for responses R.7(e).1 and R.9(a).1. Whereas in case of Q.7 the percentage of subjects giving correct response is very low, in case of Q.9 it is as high as 90 per cent. On the other hand, high percentage of pupils opting for response R.7(a).2 again shows the effect of the episodes emphasising the non-essential attributes of graph. This effect of the Epi-Con is also evident in respect of the responses to Q.7(b), Q.7(c) and Q.8(b), Q.8(c), Q.8(d), where the pupils have used the coordinates and not the change in coordinates (slopes) to arrive at the conclusions.

The responses to Q.8 and Q.13 are to be analysed simultaneously as the questions are similar in form, structure and content. In these cases again, it is observed that the pupils have wrongly utilised the coordinates of points to draw inferences for which change of coordinates should have been utilised. This is evident from the high percentage of pupils responding that the larger the coordinate at a given time, the larger is the velocity or acceleration of the body at that time. In fact, they have also responded that if two bodies have the same coordinates at the same time, then they have the same velocity or acceleration.

The data also show that the effect of the Epi-Con does not change much with school years and even teachers are affected by the same.

Conclusion

In this study, we have been able to demonstrate that Epi-Con is a probable generative cause of alternative conceptions (ALCONs), as manifested by a group of pupils and teachers and further, that these ALCONs are perhaps more due to the episodic nature of learning of concepts by the pupils and teaching by the teachers, rather than due to their wrong comprehension of each of the concepts when considered in isolation. The conceptualisation is seen to have forms without coherence and with boundaries without intercommunication channels. The very fact that the Epi-Con generates the same ALCONs simultaneously in a group of pupils can help in the design of curative prescriptions for implementation in classrooms.

For curative measures for dealing with graphs in kinematics, the following suggestions may be considered.

1. The essential attributes of graphs be emphasised both through problems demanding comprehension of these attributes and through innovative classroom activities.
2. It should be stressed that graphs do not represent the actual paths of the motion of a body even though sometimes there might be a resemblance.
3. It may be indicated in particular that in the case of projectile motion, the displacement-time graph resembles, by chance, the actual path of the projectile.
4. It may also be stated that the visual shape of a wave has nothing to do with the displacement-time graph of the SHM executed by each particle as the wave propagates.
5. It ought to be emphasised that velocity and speed, displacement and distance have distinctive characteristics such as (a) velocity and displacement can be positive or negative but speed and distance are always positive, (b) displacement can increase and then decrease whereas the distance travelled by a body only increases.
6. Innovative activities involving motion may be tried out in a classroom situation by asking a pupil to walk and noting down his displacement at various moments from a reference point.

In a more general framework, the following may be tried.

1. Identify the isolated episodes which are likely to have interrelations.
2. Map the boundaries of these episodes as outlined in the curriculum and textbooks.
3. Locate the points on the boundaries where channels of communication with other episodes can be opened up.
4. Design activities, problems, experiments and discussions based on the utilisation of these channels.
5. Test the coherence of concepts achieved through this process.

Finally, it has been possible to demonstrate that the Epi-Con affects the pupils and teachers in an almost similar way. It is suggested that the cross-cultural validity of Epi-Con as a generative cause of ALCONs in a group of pupils might be investigated.

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