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Integrated Mathematics and Science Instruction on Motion Problems in Grade 9 Classes*

Cihan Kılıç[1], Belgin Özaydınlı-Tanrıverdi[2]

[1] Faculty of Education, Yıldız Technical University, Türkiye
[2] Faculty of Education, Kocaeli University, Türkiye

Correspondence: Cihan Kılıç, E-mail: cihankilic88@gmail.com

Abstract
The integration of mathematics and science in teaching facilitates student learning, engagement, motivation, problem-solving, critical thinking, and real-life application. Although curriculum integration is theoretically desirable for many educators, what to integrate and how to integrate are often the big questions facing teachers working within education systems premised on a culture of segregated subject delivery. This quasi-experimental study reports on a 2-week inquiry of the implementation of an integrated unit of learning on motion problems, within upper secondary education in Turkey. In order to reveal the effect of the instruction on students with different mathematics achievements, the study was conducted with 131 students in two different schools. In the design of the integrated unit, continuum model of learning and four-stages of learning model were employed. The study employed a quantitative approach and examined the key aspects of the practice of the integration of mathematics and science teaching. In light of the data obtained, it was concluded that teaching the subject Motion Problems through an integrated design had a positive effect on students' learning for the experimental groups in each school.

Keywords: Curriculum and Instruction, Integrated Teaching, Motion Problems, Upper Secondary Education, Mathematics Education, Science Education

1. Introduction

Some 65 years ago, Smith (1955) published an article in Mathematics Teacher in which he stated,

> The elimination of mathematics in science courses and the weakened position of mathematics in the curriculum are often justified on the ground that a numerical approach is too abstract, too 'difficult' for our new high school population. We believe that the difficulty in both can be alleviated by encouraging a constant interplay between the concrete applications in physics and mathematical reasoning.

* This study emerged as a result of the reanalysis of the data in the thesis completed in 2018 by the first author under the supervision of the second author, in line with the purpose of the research. Part or all of the research has never been published anywhere before. In Turkey, as with all dissertations made in the field of education before February 2019, this thesis received approval from the Kocaeli Governorate and from the provincial directorate of national education.

> Mathematics-physics, a relatively unexplored area, may offer an opportunity for both algebra and physics to regain their stature in the modern curriculum. (p. 537)

Now, 65 years on, one might consider, through the integration of mathematics and science, that teachers have made progress in helping students to not only see the important connections between these two disciplines, but also to understand how one discipline can support learning in the other. It is true that integrating elements of mathematics and school science as a means of strengthening students' understanding of many connections that link science and mathematics has long been accepted amongst educationalists (Treacy & O'Donoghue, 2012). Furthermore, the natural overlaps between school science and mathematics, as Smith (1955) mentioned, have led some educators to suggest that these two subjects should be integrated to the extent *that it becomes indistinguishable as to whether it is mathematics or science* (Berlin & White, 1992, p. 341). However, the literature indicates that there are challenges to fostering such strong interdisciplinary connections, such as time, resources, a culture of segregated subject delivery, lack of teacher education/professional development, and pressure on teachers to prepare students for external discipline-based examinations (Berlin & White, 2012; Czerniak, 2007; Frykholm & Glasson, 2005; Harris et al., 2009; Pang & Good, 2000). It has also been suggested that *what to integrate* and *how to integrate* are the big questions facing teachers (Authors, 2019). Therefore, there is a need for new research to propose an instructional design which contributes to the relevant literature in terms of which topics should be integrated, and how to plan such a course. Accordingly, a central aspect of the current research was the development of an integrated unit of learning on the topic *Motion Problems* in school mathematics with the topic *Motion* in school physics in the Turkish upper secondary education system, which is premised on a culture of segregated subject delivery.

Research on integrated education in Turkey are often limited to theoretical studies or studies reflecting the opinions of teachers regarding integrated courses (Turna & Bolat, 2015). Therefore, the purpose of the current study is to propose an instructional design for a mathematics lesson undertaken in the Turkish upper secondary education context, with a focus on classroom implementation within the "normal" school context, *e.g., prescribed central syllabi, school resources, timetabling,* etc. The study aims to explore if the ninth-grade students can learn the subject of *Motion problems* in their Mathematics course better by relating it to the subject of *motion* in their Physics course. Therefore, the current study aims to answer the following research question:

- What is the effect of a course prepared with an integrated teaching approach for the ninth-grade mathematics lesson on *motion problems* on the students' performance?

The findings of this research are intended to set an example for researchers and educators in creating their own integrative course designs. Also, the current study can be viewed as an account of the key aspects to be taken into consideration for planning similar types of instruction in the future.

1.1. Integrating mathematics and science teaching

Many of the rationales for integrating school subjects are based on the premise that within today's complex, challenging, and globalized world, citizens need to draw upon multidisciplinary knowledge in order to understand and address the multifaceted issues they face (Maass & Engeln, 2019; Ríordáin et al., 2016). Research has demonstrated that curriculum integration provides endless opportunities for more relevant, less fragmented, and more stimulating experiences for learners (Furner & Kumar, 2007). It also helps students form a deeper understanding, more readily see the *bigger picture*, recognize the relevance to real life, and to make connections among central concepts (Bosse et al., 2010). School curricula, however, usually compartmentalize such knowledge into isolated disciplines (Breiner et al., 2012; Rennie et al., 2012), and implementing an integrated approach within an existing education system that has a very established, segregated, and discipline-based structure can necessitate profound restructuring of both curricula and lessons/content (Nadelson & Seifert, 2017).

Integrating elements of Mathematics and Science courses has long been an issue of discussion amongst education groups such as the National Council of Teachers of Mathematics (NCTM), the National Research Council (NRC), the Curriculum Corporation (Australia), and the School Science and Mathematics Association (SSMA) (Treacy & O'Donoghue, 2012), and is a practice that has already been endorsed by a number of academicians. In their historical analysis of mathematics and science integration, Berlin and Lee (2005) recognized the uniqueness of each discipline and concluded that a symbiotic relationship exists between science and mathematics. Science and mathematics are two closely related systems of knowledge, both are linked to the physical world, include shared concepts, and both require knowledge and skills to facilitate relating and therefore learning (Bower & Ellerton, 2004). Mathematics can enable students to achieve a deeper understanding of science concepts by providing ways to quantify, whilst science can provide students with concrete examples of abstract mathematical ideas (Basista & Mathews, 2002; Osborne, 2014; Park-Rogers et al., 2007). In other words, science provides mathematics with interesting problems to investigate, and mathematics provides science with powerful tools to use in the analysis of data (Rutherford & Ahlgren, 1990).

With their focus on instructional practices in integrated mathematics and science education, constructivist theories suggest a major shift from learning science and mathematics as an accumulation of rote facts and procedures to learning science and mathematics related to authentic contexts (Thibaut et al., 2018). This category of learning theories states that knowledge cannot be transmitted, but rather is actively constructed by students based on their existing ideas and their experiences while for behaviorist theories, the underlying theory for segregated curricula, learning is considered an individual process (Ertmer & Newby, 2013). Frykholm and Glasson (2005) claimed that when mathematics and science learning is segregated, the context of the investigated phenomenon may be lost, and students are therefore less able to resolve real-world problems. The integration of mathematics and science, on the other hand, provides the opportunity for students to apply the discipline to real situations; as situations that are relevant to the students' world, and which are presented according to the students' own perspective (Davison et al., 1995). As such, it can help students to build upon their problem-solving and critical thinking skills, to help make the curriculum more relevant to them, and to help them appreciate how different subjects can be applied together in order to solve an authentic problem (Czerniak, 2007; Pang & Good, 2000). The relevant literature also indicates that mathematics and science integration can positively affect student achievement (Gentry, 2016; Ríordáin et al., 2016), and that it is critical for the motivation and engagement of students in meaningful learning (Furner & Kumar, 2007; Wilhelm & Walters, 2006).

However, previous studies have identified a set of interrelated barriers to integration, which are reported as *perceived barriers* by Czerniak and Johnson (2014, p. 403), including school-based structural factors such as time, resources, a culture of segregated subject delivery, lack of time to plan with other teachers, pressure on teachers to prepare students for external discipline-based examinations, and poor teacher content knowledge and pedagogical content knowledge (Berlin & White, 2012; Czerniak, 2007; Frykholm & Glasson, 2005; Furner & Kumar, 2007; Harris et al., 2009; Margot & Kettler, 2019; Nadelson & Seifert, 2017; Nagle, 2013; Offer & Vásquez-Mireles, 2009; Pang & Good, 2000; Ríordáin et al., 2016; Stinson et al., 2009; Tchoshanov, 2011; Wong & Dillon, 2019). Most teachers are subject specialists and therefore do not possess the requisite knowledge or confidence required to integrate the language, methods, concepts, or content of another discipline (Basista & Mathews, 2002; Weinberg & Sample McMeeking, 2017). In addition, curriculum writers and teachers are faced with the challenge of finding and/or developing integrated units appropriate to the curriculum (Lonning & De Franco, 1997). To complicate matters, since many educators do not understand curriculum integration that well, no clear formula for such an implementation exists, and the organizational structure of the departments presents a significant obstacle to collaborating with others (Drake & Burns, 2004).

As the reviews of the relevant literature demonstrate, the implementation of integrated mathematics and science lessons is likely to be influenced by factors such as teachers' level and the school environment. The current study seeks to make use of *integrating* the study of *motion* in mathematics and physics for the students, whilst also looking to frame the study in terms of measurable student outcomes. Thus, the current study has a number of specific focal areas in order to identify the aspects of practice, what subjects should be integrated and how they should be integrated, and to facilitate the integration of mathematics teaching with science at the upper secondary level. The researchers in the current study aimed to examine this phenomenon within Turkey's centralized, mandated syllabi, with one individual teacher implementing integration on their own within the normal working confines of a school. Since the current study explores enacting a response to links identified between these two areas of the curriculum, going beyond the realm of theoretical study or reflecting teachers' opinions, the current study's findings aim to contribute to the literature regarding the integration of mathematics and science.

1.2. Context of The Study

1.2.1. Upper Secondary Education in Turkey

The Turkish educational system operates on a centralized model and is based on a significantly prescriptive curriculum. The Turkish curriculum is centrally devised by the Turkish Board of Education and is administered by the Turkish Ministry of National Education. A centralized national Upper Secondary Transition Examination (LGS) is applied at the end of the lower secondary education (i.e., at the end of Grade 8) for entry to high school (i.e., from Grade 9 to Grade 12). Biology, Physics, and Chemistry lessons taught under a combined Science discipline in secondary school are compartmentalized as of the ninth grade. Both mathematics and science are compulsory subjects for all students throughout upper secondary education (i.e., high school). Apart from the curriculum, other resources that teachers employ in the teaching of their courses include course textbooks as determined by a committee appointed to the Turkish Board of Education, and are compulsory in all public schools. Traditionally, the departments of Mathematics and Science in Turkish schools operate in isolation, with little or no cooperative planning taking place in terms of overlapping topics between the two disciplines. In addition, although the concept of integration was included both qualitatively and quantitatively in the previous Upper Secondary Education Mathematics Curriculum to a significant degree, the current curriculum, which was introduced in Turkey in 2017, provides for a lesser degree of cross-disciplinary integration (Milli Eğitim Bakanlığı [Turkish Ministry of National Education], 2017b). In other words, whilst teachers may be considered to possess the required competencies to integrate certain elements of mathematics and science courses, the current curriculum largely does not support its enactment. Also, the related literature from the Turkish context has demonstrated that whilst many educators may desire the integration of some topics in mathematics and physics, there are certain challenges, as previously mentioned in the Introduction section of the current study, that may prevent its successful implementation (Dervişoğlu & Soran, 2003; Authors, 2019; Özhamamcı, 2013).

1.2.2. Participating teachers

For the design phase of the integrated course, the researchers worked with one physics and two mathematics teachers on the design of the course, the arrangement of the worksheets, and for the achievement test. During the implementation phase, two mathematics teachers involved in the design phase of the course applied the design within their classes. The physics teacher who worked on the design phase did not participate in the implementation phase. Notably, within the active implementation of the classroom element of the current study, there was no flexibility given in either the timetable or the class schedule.

1.2.3. Ninth-grade Mathematics and Physics curricula/ textbooks

Before designing the integrated unit of learning, the Turkish ninth-grade Mathematics and Physics curricula (Milli Eğitim Bakanlığı [Turkish Ministry of National Education], 2017a) were examined, as well as the relevant textbooks specified in the curricula for the topic of *motion*. As a result, the following conclusions were reached:

- In the ninth-grade Physics curriculum, the units are listed as “Introduction to Physics,” “Matter and its Properties,” “Motion and Force,” “Energy, Heat, and Temperature,” and “Electrostatics.” The *Motion and Force* unit, which is among the subjects included in the first semester, carries the most lesson hours of the curriculum (20 out of 72 hours in total). In the ninth-grade Mathematics curriculum, motion problems are included within the *Equations and Inequalities* unit, which forms part of the second semester, and covers a maximum of 6 hours from a total of 24 lesson hours in the curriculum allocated to motion problems.
- In the physics curriculum, the *Motion and Force* unit includes the classification motion types; recognizing the concepts of position, distance, displacement, speed, velocity, time, and acceleration, and the relationships between them; relating the concepts of position, velocity, and time for smooth linear motion; drawing and interpreting mathematical models related to motion through graphics; recognizing the concept of average speed and the concept of acceleration / deceleration; drawing and interpreting velocity-time and acceleration-time graphs; and, calculating average speed from graphs. The mathematical model of acceleration is provided both within the Physics curriculum and the associated textbook, but the mathematical calculations are excluded.

- The velocity-time and location-time graphs are excluded from the mathematics curriculum, although they may relate to motion problems.
- The concept of average speed on motion problems is included in the mathematics textbooks; however, they only involve mathematical operations and graphics are not used.
- The concept of acceleration is excluded from the mathematics curriculum, with motion problems taught using examples of constant speed movements and/or calculations, although this is not the only type of speed encountered in real life. In addition, smooth acceleration and deceleration calculations are excluded from the textbooks. As a result, students may experience difficulties in establishing links between mathematics calculations and daily life.
- The concepts of *catching up* and *collision*, which are considered common in daily life, are excluded from the mathematics curriculum and from the applicable mathematics textbooks. However, if the motion problems were explained by way of using graphics, students may have an easier time understanding how moving objects collide or catch up, and may therefore establish more connections with real-life events.
- To summarize, real-life examples related to *motion* are presented in the Physics course, but the process of analyzing them is left to the mathematics course.

1.2.4. Design of the integrated unit of learning

Since there are various views and models which deal with the integration of science and mathematics, there is no single agreed view regarding the ideal integration (Czerniak, 2007; Morrison & McDuffie, 2009). In the current study, the design and implementation of the integrated unit on learning draws upon two theoretical concepts: (1) the continuum model in the integration of the design and the intended implementation of the integrated unit; and (2) the four-stage model within the design of the integrated unit.

1.2.5. Continuum model of integration

In this research, the design and intended implementation of the integrated unit of learning draws upon the continuum model, as developed by Lonning and DeFranco (1997), which accepts the integration of science and mathematics in a single continuum, as illustrated in Figure 1.

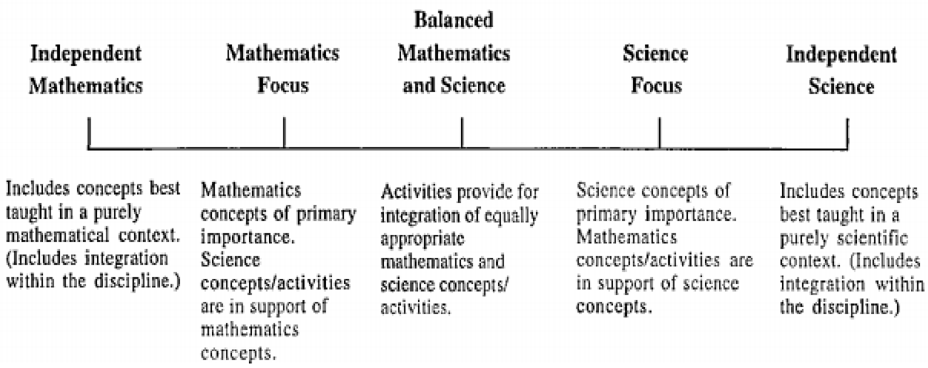

Figure 1: Continuum of integration of mathematics and science concepts/activities (Lonning & DeFranco, 1997, p. 213)

As can be seen in Figure 1, the category at the center of the continuum represents the total integration of both the Science and Mathematics disciplines. At the two opposing ends of the continuum, the Science and Mathematics courses coexist independently, with an emphasis on integration within the discipline. At the intervening points between the two ends and the center, either science or mathematics is at the center whilst the other discipline is used as a vehicle. Concerning how to integrate mathematics and science, one of the recommendations that Berlin and White (1992) and Davison et al. (1995) made was to integrate where an overlap exists between the course content of both mathematics and science, especially on topics that are historically covered or developed in greater depth. *Mathematics focus*, which is the basis taken for the current research, is an approach in which the mathematical outcomes are considered as the basis, whilst the science is regarded as a supplementary discipline. Mathematical outcomes can be reinforced by transferring scientific content at the appropriate points. In other words, mathematical concepts are deemed to be of primary importance, whilst the science concepts support the mathematics. In the current study, the concept of *Motion Problems* in mathematics was integrated with the concept of *Motion* that was initiated in the Physics classroom. Rather than attempting to fully integrate the learning, which would necessitate that both teachers possess strong levels of content knowledge across both disciplines and would require flexible curricula and course hours, the teachers collaborated on the development of certain curricular units based on the connections established between mathematics and science.

1.2.6. Four-Stage Model

The four-stage model of Jacobs and Borland (1986) was also taken into account in the planning of the integrated course, as: (1) Determination of the subject; (2) Brainstorming; (3) Establishing guidance questions for research; and, (4) Designing and implementing activities.

In the determination of the subject, the findings of three studies were used, in which each referred to the opinions of teachers on the integrated approach (Başkan et al., 2010; Kim & Aktan, 2014; Authors, 2019). According to these studies' findings, one of the most relevant subjects between mathematics and physics for educators was the topic of *Motion.* In addition, since the multidisciplinary general science approach is used in Turkish lower secondary education, it was deemed appropriate to position the integrated mathematics-physics unit in Grade 9 (upper secondary) for the current study, as the transition year for segregated subject delivery. Two mathematics teachers, one physics teacher and the researchers each participated in the brainstorming stage, and consensus was reached with regards to how the courses could be integrated according to the *Mathematics Focus* approach of the continuum model.

In the third stage, various questions were developed so as to contribute to permanent learning through creating guidance questions for the research. Some of these questions were asked directly by the teacher, whilst others were applied to the students in the form of worksheets during the activities. For the final stage, an integrated unit of learning was prepared by the researchers and teachers as a design and implementation activity. In order to avoid the so-called *potpourri problem*[1], which is one of the most commonly encountered problems in the design of integrated courses, the participating teachers actively took part in the design work, in determining the nature and degree of the integration, as well as the scope and order of the study.

1.2.7. The integrated unit of learning

The integrated unit of learning consisted of six lessons in total to be practiced over a period of 2 weeks (see Table 1). The purpose of the integrated unit of learning is to facilitate the development of students' mathematical concepts and skills through concrete real-life experience, and to demonstrate the connectivity and relevance between both subjects with a view to engaging students in meaningful learning (Furner & Kumar, 2007). The lesson plans were underpinned using the theoretical frameworks detailed in the two previous subsections, whilst demonstrating the linkage, interconnection, and development of motion problems (speed, distance, and time) in mathematics lessons initiated during physics lessons, and a framework as introduced in the section entitled *Ninth-grade Mathematics and Physics curricula / textbooks.* In the creation of the Integrated unit, the students' preexisting background information regarding the *Motion* topic from the first semester's Physics course was taken into consideration. How the students' prior knowledge acquired from their physics lessons was used within the integrated lesson is presented in Table 1.

[1] For example, if the subject is Ancient Egypt, it will necessarily encompass a bit of history about Ancient Egypt, take a look at the literature, plus some aspects of the arts etc. Jacobs (1989) criticized this approach for its lack of focus, referring to Bloom and Hirsh, and named this as the "potpourri problem." According to Jacobs, unlike disciplines with an inherent scope and sequence, there is no generalised structure to interdisciplinary work.

Table 1: Students' prior knowledge of motion from physics lesson and how it is applied to mathematics lessons

Elements covered in physics lesson about motion (students' prior knowledge)	Integrated mathematics lesson
Classification of motions of objects (very fast, accelerating, decelerating situations)	In order to draw attention to the subject, based on the examples in a newspaper article about objects moving very fast in space, objects that move at a constant speed, as well as objects that accelerate, and slow down are mentioned.
Speed-time and position-time graphs	In the lessons, the students are reminded about the related concepts of the physics lesson using different teaching methods (e.g., question-answer, brainstorming, case study, etc.) in order to relate their previous learning to new learning. Besides mathematical expressions (non-graphical), graphics are also used in teaching the concepts of position, travel, displacement, and motion (through lectures and problem solving). In this way, students are able to make comparisons between both situations.
Speed–time and position–time graphs Object acceleration and deceleration (accelerated motion)	The concept of acceleration is explained using acceleration and deceleration events. Various graphs such as velocity–time and position–time graphs are used. Graphs and mathematical expressions are used to calculate the average velocity of an object moving with a constant velocity. How the average velocity of the objects moving with a constant velocity as well as of the objects accelerating and decelerating is calculated and explained. In the calculation of average velocity, in addition to the constant velocity, the average velocities of the accelerating and decelerating objects are explained with the help of graphs.
Situation of one moving object with respect to another Catch up /collision situations via accelerating/decelerating motion	Collisions of vehicles moving in the same direction or towards each other at a "constant speed," as well as the collision situations of vehicles accelerating or decelerating are explained (e.g., when a faster-moving vehicle hits the vehicle in front). Both non-graphical and graphical (velocity–time, position–time) examples of these situations are given. In order to correlate the subject of movement with daily life, an explanation of the situation of a mobile object with respect to another, which is not included in the content of the mathematics lesson, is included in the content of the integrated course.

A description of the integrated unit applied to the two experimental groups is presented in Table 2.

Table 2: Description of integrated unit

	Sequence and description of lessons
Lesson 1	Lesson purpose: to provide students with a holistic perspective to help them realize the importance of and need for motion in daily life, and how mathematics and physics are two closely-related systems. Apart from objects moving with "constant speed" (mathematics lesson content), objects that accelerate and decelerate are also mentioned. In addition, very fast-moving objects in space are mentioned, and a brainstorm conducted on what could happen when objects move extremely fast, i.e., close to the speed of light. These issues are emphasized by referring to the ideas and theories of the late renowned astrophysicist, Professor Stephen Hawking.
Lesson 2	Lesson purpose: to provide students with key skills required for calculating the average speed of objects in constant motion. The basic concepts of the subject are provided, together with an explanation of constant motion. The basic speed equation, $S = D / T$ (S: Speed, D: Distance, T: Time) and its relevant units are explained. On this, units of speed, distance, and time are given and applications conducted about how unit conversions are made. No direct relationship is established with the Physics course.

	Sequence and description of lessons
Lesson 3	Lesson purpose: to explain the movement of two objects moving towards each other at a constant speed, and the position of objects moving at a constant speed around a circle. Situations related to vehicles moving in the same direction or towards each other at a "constant speed" are included. Sample questions regarding the vehicles' encounter times when moving on the same road are resolved. Applications of the basic speed equation (S = D / T) are included in the questions on this topic. No direct relationship is established with the Physics course.
Lesson 4	Lesson purpose: to further develop the students' understanding of graphical concepts (slope and area) in relation to speed, distance, and acceleration in mathematics. This involves solving sample questions on the use of velocity–time and position–time graphs that students will have learned initially in their previous physics lessons. The concepts of slope and area used as speed and distance in mathematics are explained, together with example questions. Average velocities of objects in constant motion are taught using graphics. Additionally, the concept of acceleration is revisited using questions on average speed according to accelerated and decelerated movement.
Lesson 5	Lesson purpose: to enable students to establish more realistic connections between the subjects and daily life. Objects moving with respect to other moving objects, and the collision cases of accelerating or decelerating vehicles are explained, e.g., a faster moving object hitting an object moving in front of it. Moving objects are explained according to different reference points, with the concepts of catching up and collision explained both transactionally and graphically.
Lesson 6	Lesson purpose: to increase the students' familiarity with the average speed formula through mathematical tasks from a worksheet focused on speed, distance, and time. Tasks involve real-life applications to make the material relevant and meaningful. Sample applications about average velocity calculation and collision situations use velocity–time and position–time graphs. The aim being that students can associate graphics learned in the physics lesson and repeated in the mathematics lesson.

A description of the mathematics lessons applied to the two control groups is presented in Table 3.

Table 3: Sequence and description of the mathematics lessons

	Sequence and description/ purpose of lessons
Lesson 1	Lesson aim: to introduce the basic concept of motion. In order to attract student learners' attention, questions are asked related to the importance of the concept of motion in daily life, and a brainstorming activity is performed. Potential differences between the states of a vehicle moving at a constant speed, accelerating, or decelerating are discussed. The movement of a vehicle at "constant speed" is used to explain the basic concept of motion. The basic equation of speed, S = D / T (S: Speed, D: Distance travelled, T = Time elapsed) is explained; with units of speed, distance, and time applied as unit conversions.
Lesson 2	Lesson aim: to teach the basic components of movement, with questions included based on the basic velocity equation, i.e., the displacement of a vehicle moving at "constant speed." The questions include expressions about the displacement of a vehicle moving at a constant speed between two points, with students tasked with finding a third value from two given values (i.e., distance, time, and speed).
Lesson 3	Lesson aim: to introduce the concept of "average speed," with preliminary information obtained by questioning why average speed is needed and how it can be calculated. Then, how to calculate the average speed of a vehicle moving at "constant speed" is explained, together with the appropriate formula. The subject is then reinforced by solving non-graphic questions, with examples given on calculating the average speed of vehicles moving at different speeds on different roads.
Lesson 4	Lesson aim: to address situations related to the encounters of vehicles moving in the same direction or towards each other at "constant speed," with sample questions about the encounter times of vehicles moving on the same road. The questions include applications of the basic speed equation (S = V / T) introduced in Lesson 1.

	Sequence and description/ purpose of lessons
Lesson 5	Lesson aim: to readdress the vehicular encounters taught in Lesson 4 on circular roads (i.e., encounter situations of vehicles moving towards each other at "constant speed" on a circular road), reinforced through the solving of examples.
Lesson 6	Lesson aim: to readdress the concept of constant speed (as learned in previous lessons), exemplified in different situations. For example, sample questions about vehicles passing through a tunnel or of a person moving on a river.

2. Method

2.1. Research Model

In the current study, a quasi-experimental research design was applied according to a pretest–posttest approach with control and experimental groups taken *as-is* from their institutions or from their natural environment (Creswell & Creswell, 2017). The data from the two schools were analyzed separately. In addition, in order to elicit a deeper understanding of the participant students' development of their motion problem solutions through the integrated design, *post-hoc content analysis* of selected papers with large gain scores on specific items was conducted.

2.2. Participants and Context of Research

The study's participants consisted of 131 ninth-grade students from two different Anatolian high schools in the Kocaeli province of Turkey. In the first school (PAL), the experimental group (PAL Ex) consisted of 34 students, whilst the control group (PAL C) had 32. At the second school (KAL), the experimental group (KAL Ex) consisted of 33 students, whilst the control group (KAL C) had 32. In forming the study group, convenience sampling was applied, which aimed to select individuals and groups to be researched most easily (Creswell & Plano Clark, 2011). This method was employed in order to see the effect of the study's experimental process on two different schools that shared similar backgrounds, but differed according to LGS examination scores at the institutional level. The LGS scores for the first school, PAL, were considered to be *low moderate/moderate* (average score: 407.60), whilst the second school, KAL, had an institutional average score of 478.12, which was *the highest* amongst the 54 Anatolian high schools in the Kocaeli province in the year that the study was conducted. To put those scores into context, the lowest average institutional score that year was 362.76.

In determining the individual teachers who would conduct the experimental procedure, the teachers' seniority (13 to 14 years of teaching experience) and their voluntary agreement to take part in the study were taken into consideration. In order to minimize errors during the experimental process, both the experimental and control groups at each participant school had the same physics and mathematics teachers. In order to assess whether or not the courses were conducted in accordance with the design of the unit, i.e., in view of treatment fidelity, the researchers were also involved as direct observers in both the experimental and control groups' activities at both schools and noted the absence or presence of each treatment component (Lane et al., 2004).

2.3. Data Collection Instrument

An achievement test was administered in accordance with the objectives of the lessons defined in the curriculum. At the stage of developing the test, a table of specifications was first prepared and then opinion was sought from two Mathematics Education experts, two Physics Education experts, and one Assessment and Evaluation expert, each of whom worked at …. University, in order to ensure validity of the study's scope. Preliminary application of the 20-item achievement test was conducted at the second school (KAL) with 71 students from the 10th grade who had completed that subject in their previous academic year. Following item-level analysis using MS Excel, three questions whose item difficulty was assessed as between .20 and .30 were excluded from the test. The remaining 17 items had a mean difficulty of .48, a mean discrimination of .47, and a KR20 reliability coefficient of .72. Accordingly, the achievement test can be said to be of moderate difficulty, and a highly distinctive and reliable test. MS Excel was used to conduct the study's reliability analysis, item difficulty index, and item discrimination index of the achievement test.

In applying the data collection instrument, in order to test whether or not the students made connections based on the common central concept of *motion* and to interpret its different expressions, six pairs of questions (total 12 questions) were prepared on the same content, but according to different styles (e.g., Question 8 and Question 11 in Appendix). In other words, six questions were expressed in mathematical terms and six based on graphics. Two other questions in the test were solvable using only mathematical formulae (e.g., Question 3 in Appendix), and two could be resolved by analyzing graphics which the students had previously learned in their Physics course prior to the experiment, or from establishing proportion which they were supposed to accomplish in the mathematics course following the experiment (e.g., Question 17 in Appendix). Finally, one question could only be resolved by analyzing the graphics which had been previously learned in the Physics course (see Question 7 in Appendix). This means that nine questions in the achievement test could be resolved from the outcomes of the Physics course taken prior to the current study's experiment. Six questions (referred to as *Integrated Questions*: e.g., Question 8 and Question 17 in Appendix), whose item discrimination and difficulty index are considered high, were especially designed to understand if the students were able to integrate the outcomes of both the Physics and Mathematics courses. The achievement test administered during the data collection process was applied to all participants under the same conditions.

2.4. Data Analysis

Two mixed-factor ANOVA analyses were applied using IBMs SPSS program (version 21) to test for significant differences between the test scores of the participant groups and for changes within the groups. A significance level of .05 was taken as the basis for the analysis of the collected data. In order to examine the effect size of the analysis, partial eta square coefficients were calculated, with an effect size of .01 or close to it considered *low*, whilst an effect size of .06 or close to it was considered *medium*, and an effect size equal to or greater than .138 was considered *high* (Cohen, 2007).

In addition, whether or not the groups had normal distribution was checked as part of the data analysis. To analyze the students' achievement tests, content analysis was employed in order to evaluate the effect of the integrated unit on the students' understanding of the connections that link science and mathematics, and also the development in their solutions to motion-related problems. In the content analysis, for selection of the participants' achievement tests, extreme (or deviant) case sampling, a type of purposive sampling used to focus upon cases considered special or unusual (Patton, 2015), was used in order to elicit a deeper understanding of the participant students' development in solving the motion problems through the integrated design. First, the students' scores from the pretest and posttest for both the experimental and control groups at both schools were examined in order to provide a general framework. Then, selected answer papers were analyzed individually on the basis of each question in the achievement test.

2.5. Experimental Process

In the two schools' experimental groups, education was applied according to the integrated approach (with the relationship established by the teacher), which forms the basis of the section titled *Integrated Unit*. For the two control groups, the education was given on the basis of *Motion Problems* and with segregated subject delivery (with the relationship established by the student). In other words, the graphics in the physics lesson were not used in problem-solving for the control groups, the concept of acceleration was not mentioned, and the average speed questions were explained only with numerical operations and without the use of graphics. Since the concept of acceleration was not mentioned, situations relating to acceleration or deceleration in movement were not included in the course content, and lessons only taught according to *constant speed movement*. Relating the concepts learned in the physics lesson with the mathematics lesson is left to the student. How the lessons are handled in the control groups is included in Table 3. Following the implementation, a posttest was applied to both the experimental and the control groups in order to measure the participant students' achievement related to motion problems.

In the preliminary analysis performed to check whether or not the data of the pretest applied to the experimental and control groups were distributed normally, the results showed the data to be normally distributed, according to the Shapiro-Wilk test regimen (PAL Ex: $df = 34$, $p = .053$; PAL C: $df = 32$, $p = .070$; KAL Ex: $df = 33$, $p = .065$; KAL C: $df = 32$, $p = .070$). For this reason, independent sample t-test was used to determine whether or not a significant difference existed between the pretest results of the control and experimental groups of each participant school. The results of the analysis are presented in Table 4 and Table 5, based on the highest score obtainable being 17 points).

Table 4: Comparison of pretest scores: PAL Ex and PAL C

Group	Pretest scores (*SD*)	*t* value	*p* value
PAL Ex (n = 34)	3.17 (2.28)	.678	.500
PAL C (n = 32)	2.81 (2.05)		

Table 5: Comparison of pretest scores: KAL Ex and KAL C

Group	Pretest scores (*SD*)	*t* value	*p* value
KAL Ex (n = 33)	7.64 (3.11)	.669	.506
KAL C (n = 32)	7.15 (2.59)		

As can be seen from the preliminary results presented in Table 4 and Table 5, the pretest analysis showed that no statistically significant difference existed between the experimental and control groups of either school based on a .05 significance level ($p > .05$). This finding shows that the readiness of all four groups was similar prior to the application of the experimental process.

3. Findings

The pretest and posttest results of the academic achievement test for the experimental and control groups at the first school (PAL) are presented in Table 6.

Table 6: Descriptive statistics of pretest and posttest scores: PAL Ex and PAL C

Group	Pretest scores (*SD*)	Posttest scores (*SD*)
PAL Ex (n = 34)	3.17 (2.28)	8.32 (3.44)
PAL C (n = 32)	2.81 (2.05)	3.59 (2.36)

When Table 6 is analyzed, it can be seen that a significant difference was found to exist between the pretest ($\bar{x}$ = 3.17) and posttest scores ($\bar{x}$ = 8.32) of the Experimental Group (PAL Ex). There was also a significant difference found to exist between the pretest ($\bar{x}$ = 2.81) and posttest scores ($\bar{x}$ = 3.59) of the Control Group (PAL C). When the posttest mean scores are examined, a 4.73 points difference can be seen between the Experimental and Control groups. Based on this finding, it can be said that the first school (PAL), having low moderate/moderate LGS scores, showed an increase in the achievement levels of both the Experimental Group's students (with integrated lessons) and the Control Group's students (current curriculum based on segregated subject delivery). Whether or not these differences were statistically significant was then examined and the results presented in Table 7.

Table 7: NOVA results of pretest–posttest scores of experimental and control groups: PAL

Source of variance	Sum Sq.	*df*	Mean Sq.	*F*-value	*p*-value	η^2
Between groups	713.969	65				
Group (Ex/C)	213.860	1	213.860	27.368	.000	.300
Error	500.109	64	7.814			
Within groups	815.649	66				
Assessment (pretest–posttest)	289.679	1	289.679	50.261	.000	.440
Group assessment	157.103	1	157.103	27.258	.000	.299
Error	368.867	64	5.764			
Total	1,529.618	131				

While the effect of the integrated lesson was investigated in the experimental design, two main effects and overall effects were tested. In view of the first main effect, whether or not there was a significant difference between the students of the Experimental Group (PAL Ex) and the Control Group (PAL C), regardless of their pretest–posttest scores, was investigated and a significant difference was found to exist between the achievements of the two groups ($F = 27.368$; $p < .05$). When the effect size of the measurement between the pretest and posttest is examined, it can be seen that the change represents a high effect size ($\eta^2 = .300$). In view of second main effect, irrespective of the experimental and control groups, the difference between the students' pretest and posttest scores was investigated and a significant difference found to exist between the two measurements in favor of the posttest scores ($F = 50.261$; $p < .05$). The change found represents a high effect size ($\eta^2 = .440$) of the measurement between the pretests and posttests. As can be seen from Table 6, an increase was seen between the posttest scores of the groups.

Finally, the overall effect of the group and measurement was investigated, and a significant difference was found to exist between the pretest and posttest scores of all students ($F = 27.258$; $p < .05$), i.e., both the Experimental Group and Control Group of the first school (PAL). The change found represents a high effect size ($\eta^2 = .229$) in the measurement between the pretest and posttest. It was observed that the students' achievements differed according to the form of instruction applied, and for the integrated course (Experimental Group), the students' achievements increased significantly more than for the students in the segregated (Control Group) Mathematics and Physics courses. These results show that the integrated course had an impact on student achievement.
The pretest and posttest results of the academic achievement test for the Experimental Group and Control Group at the second school (KAL) are presented in Table 8.

Table 8: Descriptive statistics of pretest–posttest scores: KAL Ex and KAL C

Group	Pretest scores (*SD*)	Posttest scores (*SD*)
KAL Ex ($n = 34$)	7.63 (3.16)	11.93 (2.99)
KAL C ($n = 32$)	7.15 (2.59)	7.75 (4.00)

When the results presented in Table 8 are analyzed, it can be seen that there was a significant difference found between the Experimental Group's (KAL Ex) pretest ($\bar{x}$ = 7.63) and posttest scores ($\bar{x}$ = 11.93) for the second school (KAL), which had high-level LGS scores. A significant difference was also found between the pretest ($\bar{x}$ = 7.15) and posttest scores ($\bar{x}$ = 7.75) of the second school's Control Group (KAL C). When the posttest mean scores are examined, it can be seen that a 4.73 points difference exists between the students of the second school's Experimental and Control groups. Based on this finding, it can be said that the students of the second school had an increase in their achievement level for both the Experimental Group (KAL Ex) students (integrated lessons) and the Control Group (KAL C) students (current curriculum based on segregated subject delivery). Whether or not these differences are statistically significant was then examined, and the results are presented in Table 9.

Table 9: ANOVA results of pretest–posttest scores of experimental and control groups: KAL

Source of variance	Sum Sq.	*df*	Mean Sq.	*F*-value	*p*-value	η^2
Between groups	1,048.508	64				
Group (Ex/C)	177.118	1	177.118	12.805	.001	.169
Error	871.390	63	13.832			
Within groups	746.886	65				
Assessment (pretest–posttest)	194.779	1	194.779	27.867	.000	307
Group assessment	111.763	1	111.763	15.990	.000	.202
Error	440.344	63	6.990			
Total	1,795.394	129				

The results presented in Table 9 show that, regardless of the pretest–posttest scores, there was a significant difference found to exist between the academic success of the two study groups from the second school (KAL) ($F = 12.805$; $p < .05$). When the effect size of the measurement between the pretest and posttest was examined, it can be seen that the change represented a high effect size ($\eta^2 = .169$). As for the second main effect, irrespective of the second school's experimental and control groups, the difference between the students' pretest and posttest scores was investigated and a significant difference was found to exist between the two measurements, in favor of the posttest scores ($F = 27.867$; $p < .05$). The change represented a high effect size ($\eta^2 = .307$) of the measurement between the pretest and posttest at the second school (KAL). As can be seen from Table 8, there was an increase seen in the posttest scores of the combined groups.

Finally, the overall effect of the group and measurement was investigated for the second school (KAL), and a significant difference was found to exist between the pretest and posttest scores of the Experimental Group (KAL Ex) and Control Group's (KAL C) students ($F = 15.990$; $p < .05$). The change was found to represent a high effect size ($\eta^2 = .202$) in terms of the measurement between the school's pretest and posttest results. It can therefore be observed that the students' academic achievements differed according to the mode of instruction applied, and the academic achievements of the students trained with integrated design increased more than that of the students who received segregated delivery. These results show that the integrated program impacted on the students' achievement level.

In content analysis, in order to reveal what kind of differences were found between the students' solutions to motion problems in the achievement test prior to and following the implementation, 10 papers selected through extreme, or deviant, case sampling were analyzed on a question-by-question basis. Papers with the lowest pretest scores (between 0 and 4 points) and a maximum posttest score (17 points) were selected for analysis, and thereby represented the widest pretest–posttest increase differential (see Table 8). All 10 selected papers were from the experimental groups, as no paper from the control groups met the criterion. Following the initial analysis of the 10 papers, five criteria were created: (1) number of questions answered correctly in the test; (2) number of six-paired questions that were answered correctly; (3) number of questions that were solved through graphics; (4) number of questions that were solved based graphic interpretation; and, (5) number of *integrated questions* answered correctly.

Table 10: Content analysis of participants' pretest–posttest solutions to "motion problems"

Participant code	**Pretest** (correct answers/ questions answered)	**Posttest** (correct answers/ questions answered)
PAL 54	0 / 5	12 / 17 Correctly answered five paired-questions, and realized Question 11 was an alternative of Question 8 (responded with "8 is the same with 11"). Correctly answered six questions based on graphic interpretation, resolved six motion problems by drawing or using graphics, and correctly answered five *integrated questions*.
PAL 52	1 / 5 Correctly answered speed–time graph question only.	12 / 17 Correctly answered five paired questions, six questions based on graphic interpretation, resolved four motion problems by drawing and/or using graphics, and correctly answered five *integrated questions*.
PAL 58	1 / 17 Correctly answered speed–time graph question only.	12 / 17 Correctly answered all six paired questions, six questions based on graphic interpretation, resolved six motion problems by drawing and/or using graphics, and correctly answered all six *integrated questions*.
KAL 6	1 / 9 Correctly answered speed–time graph question only.	13 / 17 Correctly answered four paired questions, six questions based on graphic interpretation, and five *integrated questions*.
PAL 34	2 / 2 Correct answers not based on graphic interpretation.	11 / 17 Correctly answered four paired questions, and realized Question 10 was an alternative of Question 2 (responded with "same question as on the front page"). Correctly answered five questions based on graphic interpretation, and five *integrated questions*.
PAL 38	3 / 6 Two correct answers based on graphic interpretation, plus one integrated question.	14 / 17 Correctly answered four paired questions, seven questions based on graphic interpretation, resolved one motion problem by drawing and/or using graphics, and correctly answered all six *integrated questions*.
PAL 48	3 / 7 No correct answers based on graphic interpretation. One correctly answered integrated question.	12 / 17 Correctly answered all six paired questions, and realized Question 12 was an alternative of Question 9 (responded with "same as for Question 12"), and Question 13 was an alternative of Question 5 (responded with "it is the graphic form of Question 5"). Correctly answered six questions based on graphic interpretation and resolved one motion problem by drawing and/or using graphics, and correctly answered all six *integrated questions*.
KAL 25	4 / 12 Two correct answers based on graphic interpretation.	14 / 17 Correctly answered all six paired questions, all six questions based on graphic interpretation, resolved three motion problems by drawing and/or using graphics, and correctly answered five *integrated questions*.

Participant code	Pretest (correct answers/ questions answered)	Posttest (correct answers/ questions answered)
KAL 10	6 / 11 Two correct answers based on graphic interpretation, plus one integrated question.	17 / 17 Resolved three motion problems by drawing and/or using graphics.
KAL 12	6 / 17 Two correct answers based on graphic interpretation, plus one integrated question.	17 / 17 Resolved six motion problems by drawing and /or using graphics.

As a result of the content analysis, it can be seen that the students experienced some difficulties in solving certain questions asked in the pretest, both in quantitative and qualitative form, but following the experimental treatment their responses progressed significantly in solving the motion-related problems. The integrated approach was shown to have contributed not only to the solution of motion-related problems in mathematics, but also improved their ability to interpret graphics in physics. From the posttest results, it can be said that those students with both high and low-moderate/moderate LGS school entry scores performed better in resolving motion problems in different ways, in perceiving different interpretations of questions, and in their interpretation of graphics. According to the results of both ANOVA testing and the content analysis, the integrated course in both schools increased student success over and above that of the current curriculum courses based on segregated subject delivery.

4. Conclusion and Discussion

Since mathematics and science are regarded as important subjects for the education of upper secondary students, there are many potential benefits to be realized from integrating the teaching of these two subjects (Czerniak, 2007). The aim of the current study was to examine the key aspects of designing an integrative course for the teaching of mathematics. The researchers' interest was also to develop an understanding about what should be integrated and how it should be achieved, which are questions still considered by educators to be crucial (Authors, 2019), and especially in school systems grounded on a culture of segregated subject delivery. In other words, the current study presents an example of how one central topic can be integrated in two distinct yet related disciplines under limited conditions, with a focus on classroom implementation within a normal school context, e.g., prescribed centralized syllabi, with limited school resources and timetabling, providing compartmentalized education.

Rather than attempting a fully-integrated learning scenario, which would require both sets of teachers to possess strong content knowledge across both disciplines, in addition to more flexible curricula and course hours, the teachers collaborated on the development of curricular units based on the disciplinary connections between mathematics and science. Based on the findings of the current study, it is clear that the integrated design provides an opportunity for students to better understand the concept of *motion* within a broader context, and that the integrated course strengthened the students' ability to establish connections between two courses, even within a school culture based on segregated subject delivery and inflexible course schedules. However, the current study's results differ from the views of Dervişoğlu and Soran (2003) and also from Karakuş and Aslan (2016), who each claimed that integrated instruction could not be realized with the current restrictive course structure in operation.
One of the strengths of the current study is perceived to be in the richness of its sampling. The study was conducted with students from two different schools with different LGS entry scores. The study's results demonstrated that students from a school with an average low-moderate/moderate LGS entry score could make the same interdisciplinary associations as students from a school with a high average level of LGS entry score. In other words, the study has shown that students with historically lower levels of academic success in both these disciplines can also establish strong bonds through the implementation of the integrated lesson model.

On the other hand, the significant difference reported between the experimental and control groups in the posttest and the results of the content analysis clearly shows that students in the control groups were hardly able to see the connection between the mathematics and physics on the subject of *motion*, which supports the findings of Yıldırım (1996) and Özçelik (2015) that it is not possible for students to realize relations in learning across all subjects. Considering the results of the current study's content analysis, the results showed that students with lower levels of academic success may make greater progress in this area and go on to resolve more complex problems when a relation is made by the teacher during mathematics teaching, rather than finding that connection for themselves. Given the difficulty encountered in relation to timetabling and support structures at the school level, and teachers' knowledge and perceptions of the respective subjects, research examining the teaching and learning of mathematics within science and/or science within mathematics certainly warrants further investigation. Similarly, a key purpose of introducing such an initiative in the current study was to demonstrate the linkage and connection between the subjects. Within the Turkish K-12 education system, these subjects are taught purely in isolation. Therefore, further examination of both subjects' curricula would be beneficial in order to identify other key elements that could be integrated in future programs.

One of the most important barriers to integrated teaching is related to the teachers' own professional qualities. Most teachers are subject specialists by virtue of their training, and therefore do not possess the necessary knowledge or confidence to integrate the language, methods, concepts, or content of another discipline into their teaching (Basista & Mathews, 2002). For the teachers participating in the current study, this was their first time undertaking such an initiative within their teaching careers, and the researchers believe that any research based on integrated instruction should include both teachers and researchers working in collaboration, which was also stated by Ríordáin et al. (2016). The researchers conclude that teachers are in need of support in order that they may embrace new pedagogical and content approaches in the teaching of mathematics and science.

Another barrier to integrated teaching is that no clear formula for such implementation exists; with no single view regarding the ideal integration (Czerniak, 2007; Morrison & McDuffie, 2009). In the current study, *mathematics with science* from the continuum model of integration does not constitute total integration. Considering that this experiment was performed according to certain limitations (i.e., under "normal school conditions"), and that the association was of a medium level based on selecting examples from the subjects of physics and mathematics and selecting examples from daily life, more effective results may be obtained with lessons based on stronger and more robustly aligned correlations. While the current study has helped to broaden our understanding of how to integrate the *science for mathematics* approach within the continuum model, the researchers believe that further study is required on course plans with total integration, and the key role of the schools is to provide support to teachers to engage in these types of initiatives.

In Turkey, most academic studies on integrated teaching are theoretical, or reflect the opinions of teachers on integrated courses (Turna & Bolat, 2015). It is therefore hoped that the current study's findings will be seen as an example to follow, providing a source for researchers and educators to refer to in creating their own integrative course designs.

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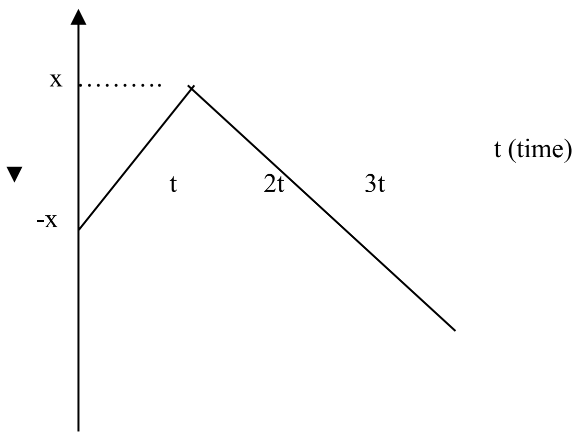
Appendix: Examples from Achievement Test

Question 3

How many seconds does it take to complete two laps around a moving track which moves at 30 m / sec on a circular track with a circumference of 0.3 km?

Question 7

x (Position)

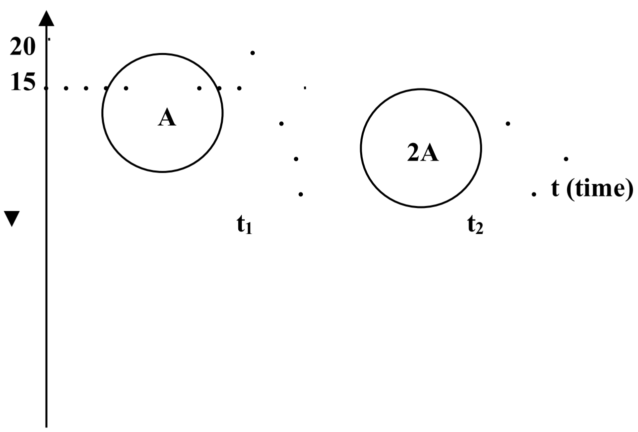


Which of the following judgements about the motion given above position-time graph is correct?

1. It is at the point where it starts moving.
2. It is about x away from the starting point.
3. Total movement time of the mobile is 3t.

Question 8

V (speed)

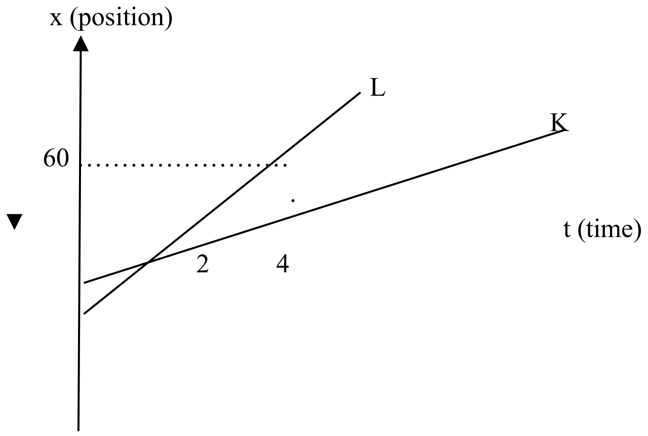


In the figure , the speed-time graph of a vehicle is given. Since the area of the rectangle on the left is A, and the area of the rectangle on the right is 2A. **What is the average speed of the vehicle during this movement?**

Question 11

A vehicle has travelled a third of the road it traveled at 20 m / sec and the rest at 15 m /sec. **What is the average speed of the vehicle during this movement?**

Question 17



In the figure, the position on-time graph of two vehicle is given. **Accordingly, how many hours after the movement of L will the distance between them be 90 km?**