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Characteristics of middle school students learning actions in outdoor mathematical activities with the cellular phone

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Learning in the cellular phone environment enables utilizing the multiple functions of the cellular phone, such as mobility, availability, interactivity, verbal and voice communication, taking pictures or recording audio and video, measuring time and transferring information. These functions together with mathematics-designated cellular phone applications facilitate authentic learning based on real-life phenomena, and widen the range of mathematical activities possible to carry out. This research shows that the cellular phone provides the mathematics students with rich, diverse and colourful learning environment in and out of the classroom. The participating students worked with the cellular phone to carry out activities involving formal mathematical phenomena and at the same time authentic real-life phenomena which they modelled mathematically. Doing so, they worked individually and collaboratively with diverse, specific and general mathematical concepts and at the same time practiced specific and general mathematical procedures, which expanded their mathematical knowledge and meta-knowledge. The cellular phone enabled the students to work with various representations of mathematical objects which encouraged them to investigate these objects independently or with the guidance of their teacher. The students also could tackle advanced mathematical objects intuitively based on their visual representation and actual realization in real-life situations.

1. Introduction

Silander & Rytkönen (2005) found that mobile devices bring a new dimension to learning and education, because they allow learning to occur in authentic contexts and extend to real environments. These authentic contexts and real environments, together with the mobile devices, enable student learning activities characterized by communication (afforded by the mobile devices), collaborative knowledge building (encouraged because of the complexity of authentic contexts), observation (facilitated by the mobile devices, especially by their cameras) and innovation (felt due to using new devices and new contexts). Thus, using mobile devices students are able to construct useful knowledge in real

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situations. This turns the mobile devices into powerful tools in the hands of students, but what characteristics of knowledge building do these powerful tools bring to students' learning? This is what this research attempts to answer.

2. Mobile mathematics education

Few years ago, educational researchers pointed at two sides of the new communication devices—the cellular phones: the ubiquity of cellular phones in every aspect of our daily lives and the novel but still little use in education (Chen & Kinshuk, 2005; Rismark *et al.*, 2007). This claim was true for the use of cellular phones in education in general and especially for their use in teaching mathematics. Meanwhile, mobile and wireless devices, especially cellular phones, have become increasingly common among young students. This made researchers point at these devices as providing new possibilities, opportunities and challenges for education (Cobcroft *et al.*, 2006), and especially for mathematics education (Yerushalmy & Botzer, 2011). Recent studies that examined the use of cellular phones in mathematics learning among pre-service teachers (Genossar *et al.*, 2008) suggest that we are at the beginning of a new era for the integration of the cellular phone in mathematics learning in and out of the classroom.

Genossar *et al.* (2008) studied the learning processes and experiences taking place within a cellular phone learning mode and examined how socio-cultural and situated learning aspects are reflected in these processes and experiences. They found that the contribution of the cellular phone environment 'lies not only in making dynamic mathematical applications more available, but also in supporting the execution of tasks that are closer to the students' experiences and more relevant to them, which has the potential to enhance experiential learning'. The authors concluded that the participants' learning experiences contributed to their personal learning, which in turn motivated this learning. Genossar *et al.* (2008) experimented with pre-service teachers, and the participants worked individually, whereas the study reported here is concerned with middle school students, and the participants worked inside and outside the classroom in various groupings.

White (2004, 2006) explored the use of wireless handheld computers to support middle school students' collaborative learning of algebraic functions in an applied context of cryptography. The wireless computer network used by the students blended multiple linked representations of mathematical functions with role-based student group work, to facilitate the learning of algebraic functions and the solving of complex mathematics problems in small groups. White (2006) reported that working in a network of handheld computers, students 'simultaneously negotiated shared utterances through a discursive network and shared objects through a device network' (p. 380). The network added to the participatory opportunities of classroom collaboration, and lower performing students, working in a network, enhanced their achievement. The collective artefacts were not only network based but also mathematically rich. White (2004, 2006) experimented with learning in a network inside the classroom, and the students were assigned specific roles at the beginning of the activity and could alternate their roles later, whereas the current study is concerned with mathematics learning both outside and inside the classroom, and the participants could decide from the beginning what roles to assume.

Roschelle and colleagues conducted several experiments using mobile devices in the mathematics classroom. For example, Tatar *et al.* (2003) examined the use of mobile devices in mathematics and science learning by implementing several activities that became possible owing to the availability of mobile devices, including: (i) distribution: sending the same document to all students; (ii) differentiation: sending different parametric definitions to each student in a systematic way; (iii) contribution: forwarding a function or mathematical data constructed by one student to a friend or teacher;

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(iv) harvesting: following the collaborative work of several students, constructing a set of functions or data that are related to each other but different; and (v) aggregation: combining functions or data that are in some way related and presenting it usually in public (anonymously or not). The study found that mobile learning promises access to applications that support learning anywhere, anytime, and that this type of learning supports both adults at the workplace and students in classroom learning. Roschelle *et al.* (2007) found that the use of mobile devices in the mathematics classroom made the class more (i) student centered, (ii) assessment centered, (iii) knowledge centered and (iv) community centered. These experiments used machines that use infrared beaming, affording spatially directed, point-to-point communication, while our experiment concentrated on the use of cellular phone only.

In the last decade, several researchers have been following the integration of applets (which are small applications that performs specific tasks, sometimes running within a larger program like the internet browser) in the mathematics classroom. Applets help students study mathematics using a constructivist approach (e.g. Pesonen, 2003). As an extension to the use of these tools within a web environment, recently new mathematical applications have become available for mobile devices, and most recently for cellular phones. These applications are called midlets. Wikipedia defines midlets as Java programs for embedded devices, generally games and applications that run on a cellular phone (Wikipedia, 2008).

As applets replaced courseware and dedicated tools in computers, midlets in cellular phones took the role of applets on the web. But the unique learning mode of cellular phones includes, in addition to the midlets, such features as the ability to take pictures, record video and audio, measure time, transfer information, use voice and text communication, forward screen content to learning mates, and send SMS and MMS messages. It seems that in addition to these features, the commonness, availability, mobility, dynamics, usability and accessibility of the modern cellular phones can make a difference in the way mathematics students build their knowledge individually and/or collaboratively in formal and/or authentic environments.

Regarding research that examined the students' perceptions of learning with cellular phones and applets, Daher (2009) examined the perceptions of middle school students about the use of cellular phone midlets and web applets in learning mathematics and how they differentiate between the two tools. Daher (2009) reported that the students were aware of the following aspects of each one of the tools: its availability, its portability, its collaboration aspect, its communication aspect, the size of its interface and its usability. The students used these aspects to describe their experience in using the tools to learn mathematics, to differentiate between them, and to decide which tool they would use in their future learning and how they would use each tool. A higher proportion of students preferred the cellular phone as a learning tool because of its portability and communicability.

Regarding research that examined mathematics learning by middle school students who used the cellular phone, Baya'a and Daher (2010) examined the conditions that influenced middle school students' learning of mathematics, when using the cellular phone, and, at the same time, the consequences of such learning. They found that what affected the students' learning in the cellular phone environment were the characteristics and technologies of the cellular phone, the requirements and topics of the mathematical activities, the learning setting (inside or outside the classroom), the intention of the researchers who participated in the teaching processes, and the involvement of the school principal and the coordinating teacher. The consequences of the mathematics learning in the cellular phone environment were as follows: the students took control of their learning, they connected mathematics with real-life phenomena, they developed a new approach to mathematics where they looked at it as an applied science and the students worked as mathematicians. The current article is interested more in describing the mathematics activities done by the participants inside and outside the

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classroom, as well as their learning processes and contexts. We will attempt to describe a model that combines between the previous factors.

3. Research rationale

Botzer & Yerushalmy (2007) depend on the literature to point out that data connectivity and communication aspects of mobile devices support social interaction, collaboration and the construction of learning. In this research, we wanted to examine the influence and actual possibilities which the cellular phone can afford mathematics learning regarding specific characteristics: learning modes, learning methods and student grouping. This would give us, together with mathematics teachers and educators, ideas how to utilize the cellular phone in order to enrich students' learning of mathematics.

4. Research questions

(1) What learning modes (authentic versus formal), learning method (self-discovery versus guided discovery) and student grouping (collaborative versus individual) does the cellular phone environment provide for learning mathematics?

(2) What mathematical concepts and procedures does the cellular phone environment enable students to engage with when utilizing the unique technology of the cellular phone?

5. Research setting

The experiment took place in two middle schools in Israel extending for 2 years. In the first year, the second researcher, who works as a pedagogical mentor in a teachers training college, guided 20 pre-service teachers in the two middle schools for 1 year of practical training. These 20 pre-service teachers constitute the third year class of mathematics and computers major in the college. In each school, the mathematics in-service teachers selected a group of 25 ninth grade students to participate in the experiment. The selection was made based on student interest and the ownership of an appropriate cellular phone. The principals of both schools added one weekly lesson with a mathematics teacher for each group, but most of the teaching at these lessons was performed by the researchers and the pre-service teachers. In the second year, one math teacher from each school selected a ninth grade class, and worked with this class during the whole year. Both the teachers utilized the cellular phone as part of their regular lessons to teach mathematics. They were accompanied by the researchers and the pre-service teachers.

6. Research process

The students used mathematical applications (midlets) that support the learning of algebra and geometry from the Math4Mobile site of the Institute for Alternatives in Education that operates within the Faculty of Education at the University of Haifa, Israel (Yerushalmy & Weizman, 2007). The Math4Mobile environment provides also SMS center that allows forwarding screen content to learning mates. In our experiment, the students used an algebraic midlet Graph2Go that enabled them to see the graphs of several templates of linear functions. After changing parameters in the algebraic form, they could see the change in the corresponding straight line. They also used another midlet Fit2Go that allowed them to set points in a coordinate system and to check whether a straight line could connect all

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of them, indicating a linear relation. They also used several tools and technologies embedded in their cellular phones to carry out various activities in the school yard and out of the school.

7. Data collection tools

We used two collection tools to collect data about the characteristics of middle school students' learning of mathematics with cellular phones: observations and interviews. These tools are described below.

7.1 *Observations*

We observed the students' learning focusing on their learning procedures. This was done by writing notes, taking pictures and recording the performed learning processes with a video camera. The students also took pictures and recorded their activities using their own cellular phones. We collected all the pictures and videos to analyse the students' learning of mathematics.

7.2 *Interviews*

The questions in the interviews probed the interviewees' learning modes (authentic versus formal), their learning method (self-discovery versus guided discovery) and their grouping (collaborative versus individual) when working in the cellular phone environment to learn mathematics. For example, to probe the grouping of the students while carrying out activities the students were asked to describe how they carried out each activity regarding their grouping, as well as to explain what influenced the way they grouped.

8. Data processing and analysis

We used the grounded theory approach (Strauss & Corbin, 1998) to identify the various aspects of learning in which the current research is interested, for example the collaboration behaviour, and to categorize the mathematical concepts and procedures with which the participants were engaged. Our use of the grounded theory approach to identify characteristics of the cellular phone mathematics learning is supported by the use of this theory by other researchers who studied educational processes that can be related to ours, for example, Yoong & Pauleen (2004), who collected and analysed data of applied research about using modern and new technologies in education. The authors used grounded theory to study the nature of e-facilitation in face-to-face and distributed electronic meetings. In another study, Cartwright & Hammond (2007) described the complex decisions and actions taken regarding the use of ICT in a primary school in the UK.

9. Research results

This section presents some of the mathematical activities that the students carried out through the experiment, and details the characteristics of the students learning actions experienced while performing the mathematical activities, in several aspects: learning mode, students grouping, learning method, mathematical procedures learned and mathematical concepts learned or used by the students. The results of the research were based on the students' interviews and watching videos and pictures of the students' performance inside and outside the classroom.

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9.1 Classroom activity: the relationship between the parameters of a linear function and its graph

9.1.1 Activity description

Through the activity, the students investigated a linear function of the form $Y = AX + B$, following the teacher's directions written in a worksheet. They were directed to fix the value of the parameter A and change the value of the parameter B in order to discover the relation between the value of the parameter B and the graph of the linear function. Then they were directed to fix the value of the parameter B and change the value of the parameter A to find out the relation between the value of the parameter A and the graph of the linear function.

The students used the midlet Graph2Go to discover the relations required. They concluded that the intersection point of the graph/straight line with the *Y*-axis is (0, B), and that an increase in parameter B moves the straight line up. They also discovered how the value of the parameter A affects the slope of the graph.

Using the cellular phone to investigate the relation between the parameters of a linear function and its graph, the students worked individually or in pairs, but when they discussed their results they did that collaboratively together with their teacher. The teacher allowed the students to choose how they want to work: individually, in pairs or in groups. One factor that influenced their choice was the possession of a suitable cellular phone which enabled working with midlets.

9.1.2 Characteristics of the students learning actions

9.1.2.1 Learning modes While carrying out the activity, the students learned inside the classroom in three modes: they learned through using technology (cellular phone), through formal manipulations and through classroom discussion.

Learning through using technology: The students used the midlet Graph2Go to manipulate the values of the parameters of the function $Y = AX + B$ in order to find out how the manipulation of the values of each parameter influences the graph of the linear function.

Learning through formal manipulations: All the classroom activities were based on manipulations of mathematical objects through calculations performed in a worksheet to find relations using pure mathematical skills.

Learning through classroom discussion: The students described the relations they arrived at, compared their findings and justified them.

9.1.2.2 Learning method The students learned through guided investigation and discovery led by the teacher.

Learning through guided investigation and discovery: The students worked with the cellular phone to investigate and discover the relation between the rule and graph of a linear function. This work was guided by the teacher's directions written in a worksheet. They discussed their findings in the classroom. This discussion was guided by the teacher in order to focus on the discussed mathematical relations.

9.1.2.3 Students grouping The students worked individually, in pairs and in groups.

Individual work: the students worked individually when they chose the template $Y = AX + B$ in the midlet Graph2Go, fixed the value of the parameter A (B) and changed the value of the parameter B (A).

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Working in pairs: the students worked in pairs when they discussed and discovered the relationship between the value of a linear function's parameter and its graph.

Working in groups: the students worked in groups when they discussed together and with their teacher the relations that they found through carrying out the activity.

9.1.3 Mathematical procedures learned by the students

Through carrying out the activity, the students learned the following mathematical procedures: fixing a parameter of a function and changing the other parameter, watching and discovering the relationship between the change in a parameter value of a function and the change in its graph, comparing algebraic representation and graphic representation of a function, describing verbally the relationship between two mathematical objects, and discussing this relationship and justifying it.

9.1.4 Mathematical concepts learned or used by the students

Through carrying out the activity, the students learned or used the following mathematical concepts: parameter of a function, graph of a function, relationship between a parameter of a function and its graph, verbal description of a mathematical relationship and justification of a mathematical relationship.

9.2 Out-of-classroom activity 1: the relationship between time since lighting a candle and its height: lighting a candle and measuring the height after different periods of time

9.2.1 Activity description

The students lit candles in the school yard, but the wind extinguished them. Therefore, the students began to discuss where they should carry out the experiment. Some groups decided to do the experiment in one of the classrooms, where other groups gathered around the candle to keep it lit up. The students in one group chose to measure the height of the candle every minute, but found that the height of the candle does not change much during this time. Therefore, they decided to increase the time period in which they measure the height of the candle again. Before each step in the experiment, the students discussed how they should perform it and what the possible outcomes of this step might be. Some groups worked faster than other groups due to proper coordination among them.

The girls in one group put out the candle each time they wanted to measure its height. When asked why they did so, they justified their doing by the need not to lose any part of the candle during the measurement.

The boys in one group measured the height of the candle without putting it out. When asked why they did so, they justified their doing by the need not to lose heat; so the results of the experiment will not be affected.

During the measurement process, one of the students in each group registered the results on a sheet of paper. The measurement was carried out by different students in the group, where every time a different student performed the measurement. When the students completed the measurement and the registration of the results, at least one of the students in the group began to assign points in the coordinate system of the midlet Fit2Go and tried to fit a linear or quadratic function to the assigned points. Further, during the experiment, one student in the group was responsible of taking pictures, while another student was recording important moments to document the experiment.

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Upon completing the experiment, the students returned to the classroom and began comparing the functions that they got. They discussed the characteristics of these functions and tried to justify why the functions had the specific characteristics.

9.2.2 Characteristics of the students learning actions

9.2.2.1 Learning modes While carrying out the activity, the students used three learning modes: they learned in authentic environment, through using technology (cellular phone) and through classroom discussion.

Learning in an authentic environment: learning authentically the students chose the best place to carry out the experiment, determined the period after which they should measure the height of the candles again, lit up the candles, measured the candles' height during certain time periods and put out the candles.

Learning through using technology: using technology, the students assigned points which fitted the collected measurements in the coordinate system of the midlet Fit2Go, and then they tried to fit a linear or quadratic function to the assigned points.

Learning through classroom discussion: as in the classroom activity, the students discussed their findings, describing the relations they arrived at, comparing and justifying them.

9.2.2.2 Learning method The students learned through investigation and self-discovery, as well as through guided discovery.

Learning through investigation and self-discovery: this learning occurred when the students measured the height of the candle in agreed intervals of time, registered the results, assigned points in the coordinate system of the midlet Fit2Go and fitted a linear or quadratic function to the assigned points.

Learning through guided investigation and discovery: as in the classroom activity, when the students discussed their findings in the classroom, the discussion was guided by the teacher in order to focus on the discussed mathematical relations.

9.2.2.3 Students grouping The students worked individually and in groups.

Individual work: the students worked individually to light a candle, to measure its height, to measure the time since lighting the candle or since the last height measurement, to watch the experiment, to take pictures or record videos, to register the results on paper, to assign proper points in the coordinate system of the midlet Fit2Go, to fit an appropriate function to the assigned points and to put the candle light out.

Working in groups: the students worked in groups to discuss the place of the experiment, to argue about the appropriate actions that should be taken during the experiment as the appropriate period of the measurement and to discuss the results of the experiment.

9.2.3 Mathematical procedures learned by the students

Through carrying out the activity, the students performed the following mathematical procedures: representing the height of the candle and the elapsing time as a point, assigning points in the coordinate system of the Fit2Go midlet, fitting a function for a set of points in the coordinate system (identifying the relationship between two mathematical objects, time and height), creating a mathematical model to

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describe an authentic phenomenon from daily life, describing the characteristics of a mathematical function, discussing and justifying these characteristics.

9.2.4 Mathematical concepts learned or used by the students

Through carrying out the activity, the students learned or used the following mathematical concepts: measurement, height (length), point, coordinate system, relation, function, function characteristics and justification.

9.3 Out-of-classroom activity 2: the relationship between the longest circumference of a rock and its height

9.3.1 Activity description

The students argued which rock to measure: small rock, large rock or a medium one, or whether they should include rocks of various sizes. When the students began measuring the circumference of a large rock, they discovered that one student was not capable of carrying out the measurement alone, so at least two students were needed to perform the measurement.

9.3.2 Characteristics of the students learning actions

What made this activity special is the fact that the measurement was carried out in pairs when the rock was of a medium size and in groups when the rock was of a large size.

9.4 Out-of-classroom activity 3: Throwing a ball

9.4.1 Activity description

In this activity, the students were divided into four groups. Each group carried out an experiment which involved throwing a ball in a different situation and measuring the time and distance that the ball travels. The situations included: throwing the ball on a flat straight surface, throwing the ball uphill, throwing the ball downhill and throwing the ball upward in the air. In each of the first three situations, four students stood in a straight line, 10 m apart from each other. They measured time in tenths of seconds using the stopwatch in their cellular phones. Some students used their cellular phones to take pictures of the experiment and record videos. Other students registered the results of the experiment in tables on worksheets prepared by the teacher. Some students assigned points, according to the registered results, in the coordinate system of the midlet Fit2Go and fitted a suitable function for the points.

When throwing a ball upward, two students stood on each floor of the first two floors of the school building. The heights of the windows in these floors were measured before starting the experiment. The students measured the time it took the ball to reach each floor using their cellular phones. The measurements were done as the ball was moving upward, and as it moved downward. One student stood in the schoolyard and measured the total time since throwing the ball until it returned to the ground. All the measurements were registered in an appropriate table, where the height ‘zero’ (the ground’s height) was registered in two situations: when throwing the ball and when the ball reached the ground downward. In the classroom discussion regarding the experiments, the students presented the results of the measurement, the mathematical models they acquired and the characteristics of these models. The students referred to the rate of change of the function, which was

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almost constant when throwing the ball on a flat surface, decreasing when throwing it uphill and increasing when throwing it downhill. They analysed the resemblance between the shape of the graph (parabola) of the function that described the relationship between the height of the ball and the time, when throwing the ball upward in the air, and the movement of the ball itself that they saw in their own eyes.

9.4.2 Characteristics of the students learning actions

The characteristics of the students learning actions in this activity were similar to characteristics described for the other out-of-class activities, but in this activity the students dealt with more mathematical processes and concepts than in the other activities. This activity also included advanced mathematical concepts as the *rate of change of a function*, especially regarding the cases when the rate increased or decreased. The students analysed this advanced concept intuitively based on its visual representation in the Fit2Go midlet. Moreover, this activity needed larger groups of students including sometimes more than five members. This was essential for carrying out the experiment and the measurements properly, and for repeating them to guarantee accuracy and consistency in the measurements.

10. Examples of students' work and discussions:

We will give now specific examples of students' work and discussions during carrying out the activities. We will consider this work and discussions in the case of the ball activity.

When throwing the ball on a flat surface, one of the groups got the results presented in Table 1. After assigning the points in the Fit2Go coordinate system, the students tried to fit a function to the points. They got the graph in Figure 1.

In the classroom discussion, the teacher raised a question about the speed of the ball when throwing it on a flat surface. The students argued that the speed would stay constant in a short distance, but it would decrease in a longer one. Specifically, they expected that the function in the case of 30-m distance would be linear. Considering the points that they got, the (36, 20) point contradicted their expectation. One student claimed that the student standing at the 20-m distance was not accurate in his measurement, which could be a result of being late in starting his stopwatch. The teacher inquired about the accurate mathematical results according to the constant speed assumption. The argument led to the results in Table 2 and Figure 2.

Another student said that every 10-m distance would probably need more time than the former one, because after throwing a ball it slows down and eventually stops. The student suggested the data in Table 3 and the graph in Figure 3 as possible.

TABLE 1. *The data gathered by one group in the case of a flat surface*

Time in tenths of seconds	Distance in meters
0	0
23	10
36	20
75	30

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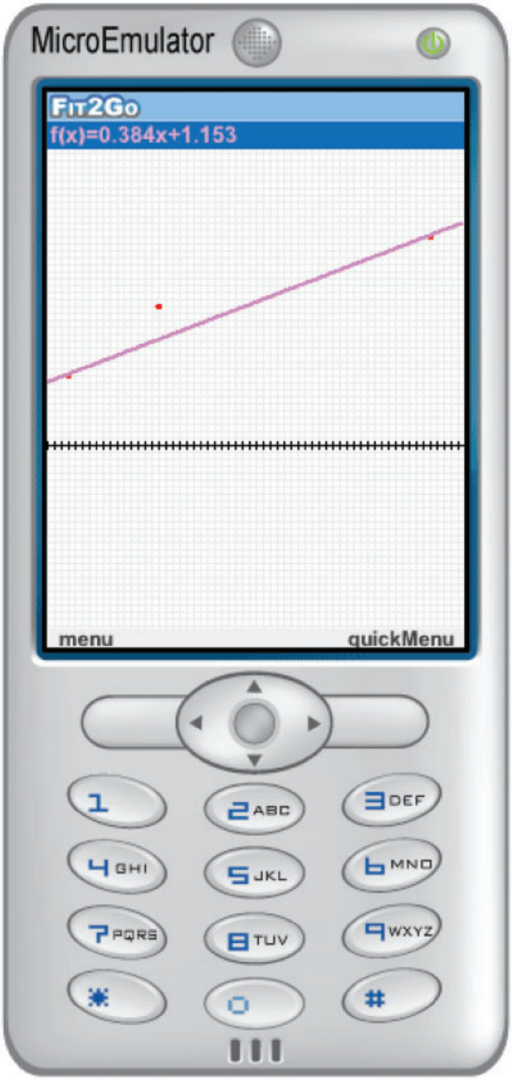

FIG. 1. A linear graph fitting the data in the Fit2Go midlet. This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.

TABLE 2. *The corrected data in the case of a flat surface*

Time in tenths of seconds	Distance in meters
0	0
23	10
46	20
69	30

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FIG. 2. The linear graph fitting the corrected data in the Fit2Go midlet. This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.

The conclusion of the discussion was that mathematical models help to understand different aspects of real-life phenomena, but building such models is not always easy because of many factors that might interfere and affect the realization of the model. The students and the teacher also argued that there could be more than one model representing a real-life phenomenon and that these models depend in part on our assumptions.

When throwing the ball upward, one of the groups got the results presented in Table 4. After assigning the points in the Fit2Go coordinate system, the students tried to fit a function to the points. They got the graph in Figure 4.

Before arriving at the above results, the students faced difficulties getting accurate measurements using their stopwatches, especially when measuring the time for the ball to arrive at each floor when

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TABLE 3. *The suggested data in the case of a flat surface*

Time in tenths of seconds	Distance in meters
0	0
23	10
50	20
80	30

FIG. 3. The linear graph fitting the suggested data in the Fit2Go midlet. This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.

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going upward and downward. Moreover, they faced additional difficulties to get the ball exactly to the second floor or to throw the ball from a height close to the ground. To overcome these difficulties, the students claimed that the time needed for the ball to move between two points is the same when moving upward or downward. Therefore, they decided to compute the time that the ball needs to go downward depending on their measurements for the upward movement. Doing so, they got Table 4 and the graph in Figure 4.

It is important to note that the students had to convert sometimes the units of the measurements because the midlet Fit2Go only allowed the assignment of points with integer coordinates. For example, they measured the floors' height in meters and centimeters, but they converted it to decimeters to make it applicable in the Fit2Go midlet. It is expected that this and other limitations of the midlet will vanish with the fast advancements of the cellular phone technologies.

11. Discussion

This section discusses the relations between the various components of the students learning actions and the factors that affected them.

11.1 Learning mode

The main factors that determined the students' learning mode when they learned mathematics with the cellular phone were as follows: the teacher's intentions and requirements and the activity topic. For example, the candle activity was possible to carry out in the classroom, but the teacher required performing it with the other out-of-classroom activities. Further, learning through classroom discussion was the choice of the teacher who instructed the students to discuss their results with her in the classroom. Baya'a & Daher (2010) pointed out that the researchers' intentions were one of the factors that were behind students' use of cellular phones to carry out mathematical activities.

The activity topic affected also the learning mode; an activity on a formal mathematical topic such as the relation between the parameters of a linear function and its graph is actually a formal classroom activity, even though it could be carried out in the schoolyard or in the field. On the other hand, the rock activity could not be carried out in the classroom, so the topic of these activities obligated the students to perform them in an authentic environment.

The availability of proper technological device with appropriate software was also a factor that affected the learning mode. Learning through using technology was possible only when students had proper cellular phones with appropriate software. This effect of the capabilities of the technological devices on students learning actions is mentioned by Vinci & Cucchi (2007) who state that the cellular phone changes educational actions, because it can be used in different teaching methods and with students having different learning abilities.

TABLE 4. *The data gathered by one group in the case of throwing the ball upward*

Time in tenths of seconds	Height in decimeters
0	0
7	50
20	85
33	50
40	0

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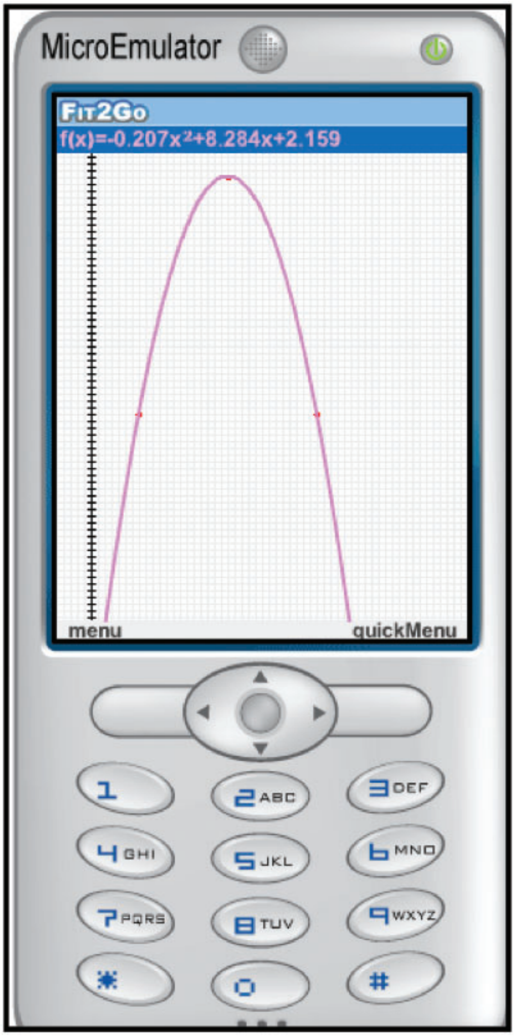

FIG. 4. A parabola fitting the data in the Fit2Go midlet. This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.

11.2 Students grouping

Four factors affected the students grouping: ownership of a proper technological device, previous learning habits, teacher's intentions and requirements, and the activity circumstances.

A student who did not own a cellular phone or owned one that did not enable working with midlets had to join another student who had a suitable cellular phone. Therefore, not owning suitable cellular phones made students work in pairs or in groups.

In the classroom activities, the teacher let the students choose the way they wanted to work together. Some chose to work individually and others chose working in pairs. This choice was based on previous learning habits that the students were used to in carrying out formal mathematics activities based on worksheets, even without using technological devices. On the other hand, in the out-of-classroom

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activities, the teacher encouraged the students to work in groups to improve their efficacy of carrying out activities which they have not experienced before. They complied with her request, but the nature of their work within the group changed according to the circumstances of the activity and the nature of the actions needed to complete it. For example, in the candle activity, the students worked in groups, but each one of them had a specific role that they had to complete individually, while in the rock activity, the students could not measure the circumference individually, so they had to work in pairs or in groups according to the size of the rock. These two examples show how the circumstances of the activity affected the grouping of the students.

We could see also that the learning mode affected the grouping of the students, because the learning modes determined the activity circumstances that influence the grouping of students as described above.

11.3 Learning method

The main factors which influenced the students' learning method were the teacher's intentions and requirements, and the activity circumstances. For example, in the classroom activity the students were required to investigate and discover formal mathematical relations using the cellular phone. The teacher based the students' investigation on worksheets that included directions intended to help them arrive at the mathematical relations. Therefore, they learned through guided investigation and discovery. From the other side, the teacher gave the students in the out-of-classroom activities only the topic of the activity; the students were left alone to adapt their learning method to the activity circumstances, which led them to investigate and discover the mathematical relations by themselves, so they had out-of-classroom self-discovery learning.

It could be seen also that the learning mode which affected here too the activity circumstances influenced the students' learning method.

11.4 Mathematical procedures learned by the students

The mathematical procedures learned by the students were of two types: specific procedures and general ones. The specific procedures included ones such as: fixing a parameter of a function and changing other parameter, watching and discovering the relationship between the change in a parameter's value of a function and the change in its graph, describing verbally the relationship between a parameter of a linear function and its graph, representing the height of the candle and the time elapsed as point, assigning points in the coordinate system of the Fit2Go midlet, fitting a function for a set of points in the coordinate system. On the other hand, general procedures included ones, such as comparing two mathematical objects, comparing an algebraic representation and a graphic representation of a function, identifying the relationship between two mathematical objects, describing verbally the relationship between two mathematical objects, describing the characteristics of a mathematical function, creating a mathematical model to describe an authentic phenomenon from daily life, discussing mathematical relations and justifying mathematical claims.

11.5 Mathematical concepts learned or used by the students

Mathematical concepts that the students learned or used in the activities were of two types too: specific concepts and general ones. The specific concepts included ones such as: length, height, point, coordinate system, linear function, parameter of a linear function, graph of a linear function, relationship

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between a parameter of a linear function and its graph and rate of change of a function (constant, increasing, decreasing). On the other hand, general concepts included ones such as function, relation, measurement and characteristics of a function.

In light of the discussion above, we could conclude that using cellular phones, while carrying out mathematical activities, enriched the students learning actions in several aspects. The students learned in various modes: in class and out of it, in modes that involved formal mathematical relations and in authentic ones that involved real-life phenomena, in modes rich in technological tools and in modes rich in classroom discussions. They experienced working in different groupings: individually, in pairs and in groups. They enjoyed learning in different methods: investigation and self-discovery by themselves or guided investigation and discovery under the guidance of their teacher. They investigated and analysed mathematical concepts of various complexities, even concepts not part of the middle school curriculum—as the increasing/decreasing rate of change of a function. This was done intuitively based on various representations of these concepts, especially the visual and algebraic representations, as well as the realization of these concepts in authentic real-life phenomena. Doing so, the students experienced working with specific mathematical concepts and procedures and at the same time with general ones that expanded their mathematical meta-knowledge. This type of knowledge would be transported to other mathematical fields that the students learn.

Figure 5 describes, based on the above discussion, the characteristics of students' learning actions when utilizing the cellular phone to carry out mathematical activities. It also shows the factors that affect these learning actions.

Different factors influenced students' learning actions: the technological tool, the teacher's intentions and requirements, the activity topic and circumstances, and students' learning habits. The research literature agrees on the effect of these factors on students' learning. Soloway (1996), for example, points out that the teacher is an important factor that enables the realization of students' learning actions, while Heugl (2004) states that technology improves several aspects of students' mathematic learning. Eklund-Myrskog (1997) points out that the learning environment, including the learning activity, affects the ways students work through their learning experiences and carrying out tasks. On the other hand, Entwistle *et al.* argue (2001) that the meanings that students give to their learning are derived from their previous experiences including their learning ones. Watkins (2001) agrees with that and adds that students' learning methods are a function of how students perceive their learning activities and their learning environment. Gravoso *et al.* (2002) say that the previous experiences of students affect the formation of their perception of learning and cause them to use a specific learning approach. These statements agree with our study where the technological tool, the teacher's intentions and requirements, the activity topic and circumstances, and students' learning habits affected the characteristics of the students' learning of mathematics.

Conclusions

The use of technology in teaching and learning is expanding, especially in mathematics education. The cellular phone is a device that attracts the attention of educators and researchers as a learning tool for its mobility, availability and commonness among young students, and because of the continuous development of its technological applications and features, which can be used and utilized also in teaching and learning. This study describes an experiment investigating the use of the cellular phone in learning mathematics in the middle school. The results show that the cellular phone provides the mathematics students with rich, diverse and colorful learning modes, where learning is done in and out of the classroom. The students worked with the cellular phone to carry out activities involving formal

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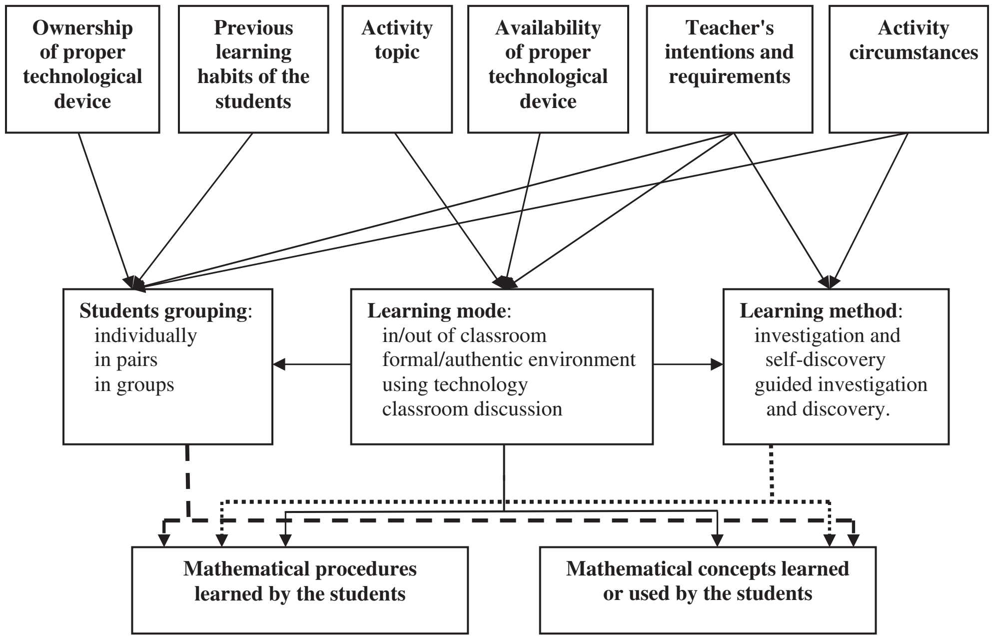

FIG. 5. The relationship between the different components of the students' learning actions in the cellular phone environment.

mathematical phenomena and at the same time real-life phenomena which they modeled mathematically. Doing so, they practiced specific and general mathematical procedures and worked with diversified specific and general mathematical concepts, including various representations of mathematical objects. Working with mathematical representations encouraged the students to investigate advanced mathematical concepts intuitively, based on the objects' visual representation and actual realization in real-life situations.

The out-of-classroom learning with the cellular phone opened various grouping options for the students and enabled them to experience diverse learning roles, which consequently led them to practice different learning actions, including different methods of investigation and discovery.

Recommendations

The research literature shows that students' use of the cellular phone in the middle schools is still in its beginning. This research shows that the utilization of this tool in learning mathematics is fruitful. Further, using the cellular phone with well-designed mathematical activities would affect positively mathematics learning and would change students' negative perceptions of mathematics, and consequently would encourage them to learn it. Therefore, mathematics teachers are invited to utilize the great capabilities of the cellular phone in learning mathematics in and out of the classroom, based on appropriate mathematical activities. This utilization would provide the students with rich, diverse and colorful mathematical environment where students investigate mathematics independently or with the direction of their teacher.

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