Pupils' choice of computer tools as affected by the learning context

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ABSTRACT

This study investigates the role of basic elements of a learning context namely: the given tasks, the nature of the provided tools, and the pupils' gender in their choice of tools provided by an open problem-solving computer environment. Pupils' choice of tools is discussed through the description of an experiment involving the interaction of 30 (14-year-old) pupils with a variety of tools provided by such a computer environment; the C.AR.ME microworld (Kordaki & Potari, 1998). These tools were designed to support pupils' learning of basic geometrical concepts namely; the concept of conservation of area and its measurement. The analysis of the data shows that the diversity of tasks invited pupils to use different tools, and that the nature of tasks asking pupils to solve them 'in any possible way' challenged pupils to use all the provided tools in alternative ways. Moreover, the nature of certain tools encouraged pupils to select those most appropriate for their cognitive development thereby expressing different kinds of knowledge they possessed. Finally, all the pupils tried to use more than two of the provided tools to perform each task, while most of them faced difficulties in using these tools in combination. Boys performed better than girls in using a combination of tools.

KEYWORDS: learning context, computer tools, pupils' choice of tools, gender differences.

INTRODUCTION

Many researchers acknowledge the role of the learning context on pupils' learning strategies (Vygotsky, 1978; Saxe, 1990; Jonassen, 2000). Basic elements of a learning context are, the learners, the learning activities, as well as the learning tools and materials provided.

Pupils' learning strategies are significantly affected by the nature and the availability of the provided tools (Vygotsky, 1978; Noss, & Hoyles, 1996). Computer technologies provide us with the ability to design appropriate learning tools which can play a highly significant role in the whole learning context (Noss, & Hoyles, 1996). Open problem-solving computer environments can integrate a variety of tools providing the pupils with opportunities to avail themselves of those most appropriate for their cognitive development. In these environments, pupils have the opportunity to express their inter- and intra-individual differences regarding the learning concepts (Kordaki & Potari, 2002). By using different tools, different external representations of a concept can be constructed by the pupils (Dyfour-Janvier, Bednarz and Belanger, 1987). Figures, drawings, geometrical shapes, text, Venn diagrams, tree diagrams, flow diagrams, graphs, tables, equations, simulations as well as computational objects are the constituent parts of different representation systems that can be integrated into a computer environment (Kaput, 1994; Dyfour-Janvier, et al., 1987). These external representation systems can become embodiments of a pupil's internal conceptualisations and can play a crucial role in their thinking (Dyfour-Janvier, et al., 1987; Noss & Hoyles, 1996). Pupils have the opportunity to express themselves through these systems thereby supporting their internal representations with external ones (Dreyfous, 1995; Sutherland, 1995). Different representation systems can be linked and interacted so that the variations in one system can affect the others, and these alterations can be visualised (Janvier, 1987; Kaput, 1994). By interacting within different linked representational systems, pupils have the opportunity to construct multidimensional, dynamic and more abstract views of the related learning concepts (Dyfour-Janvier, et al., 1987; Janvier, 1987; Lesh, Post & Mehr, 1987). Regarding a learning concept, each individual pupil has available a variety of different representation systems to express the different kinds of knowledge he/she possesses such as, intuitive knowledge, analytical as well as formal knowledge (Dyfour-Janvier, et al., 1987; Squires & Preece, 1999; Kordaki & Potari, 2002).

From a cognitive point of view, representational systems can be viewed as *transparent* or *opaque* (Lesh, Mehr & Post, 1987). An opaque representation would emphasise some aspects of the idea(s) or structure(s), and de-emphasise others; including properties beyond the idea(s) and structure(s) represented at the user interface. A transparent representation has no more meaning than the idea(s) or structure(s) it represents. Tools can be characterised as 'cognitively opaque' or 'cognitively transparent' by the kind of representations produced by using them. From a usability perspective, tools can also be viewed as '*transparent'* or '*opaque'; 'transparent'* when their use is clear and simple for the user, and '*opaque'* when their use illuminates difficulties (Kordaki & Avouris, 2001).

The learning tasks also seem to significantly affect the pupils' learning behavior (Vygotsky, 1978; Nardi, 1996; Fisher, 2000). Pupils' inter-individual learning differences also affect the kind of problem-solving strategies they develop (Lemerise, 1992). Regarding these differences the gender of pupils can play a significant role (Fennema, 1996). More specifically, gender differences still exist in the performance of tasks that require functioning at high cognitive levels. Despite the above, studies demonstrating relationships between the pupils' choices of computer-based tools and the diversity of the specific basic elements that constitute a learning context, as those mentioned above, have not yet been reported.

In this study we provide the pupils' with the opportunity to interact with the tools included in a specific open learning environment: the C.AR.ME. microworld (Kordaki & Potari, 1998). These tools are presented and discussed in the following section of this paper. Next, an experiment demonstrates relationships between pupils' choice of tools and: a) the nature of the tools used in terms of the two previously mentioned issues; their cognitive transparency and their usability b) the diversity of tasks and c) the differences deriving from pupils' gender. Finally, the findings of this study are discussed and conclusions are presented.

A MICROWORLD PROVIDING A VARIETY OF TOOLS

The 'Conservation of Area and its Measurement' (C.AR.ME) microworld is an educational software environment that has been designed as an interactive open problem-solving environment to support pupils' experimentation with the geometric concepts of conservation of area and its measurement. This environment provides a variety of tools for the pupils, giving them the opportunity to construct multiple representations of the concepts of conservation of area and its measurement. These representations are considered as qualitative, quantitative and dynamic representations of the above concepts. The tools provided are presented in figure 1 and discussed in relation to the representations that can be constructed by using them in this section.

File	Draw	Edit	Automatic Measurements	Automatic Transformations	Measurement Tools	Help
Open	Dot Square	Select Part	Areas	Square	Square unit	
	Grid					
Open		Select All	Angles	Rectangles	Rectangular	
Last	Dot Triangle				unit	
	Grid	Cut	Segments	Families of		
Save				Rectangles	Pupil unit	
Last	Draw	Paste				
	Polygons			Parallelograms	Unit iteration	
Save As		Draw an angle		Families of		
	Draw	of Rotation		Parallelograms	Counting of	
Print	Segments				units	
		Rotate		Triangles		
Exit	End Draw				Square Grid	
	Polygons	Draw an axis		Families		
		of Symmetry		of Triangles	Rectangular	
	Clear				Grid	
		Symmetry		Show numerical		
		about axis		elements	Pupil Grid	
		Erasers				

Figure 1. The general interface of C.AR.ME.

T1. Tools that simulate pupils' sensory-motor actions: A variety of tools provided to the pupils to construct different representations of equivalent areas by manipulating them without the use of numbers. These constructions can be realised by using the tools of '*Select All'*, '*Select Part'*, '*Cut*', '*Paste*', '*Rotate*', and '*Symmetry*'. These tools are presented under the 'Edit' column, in Figure 1 and permit direct manipulation of shapes. These tools can be used by the pupils to construct equivalent areas in two ways: changing only the position of a figure and splitting an area into its non-overlapping parts and recomposing these parts to form new equivalent shapes, as shown in figure 2.

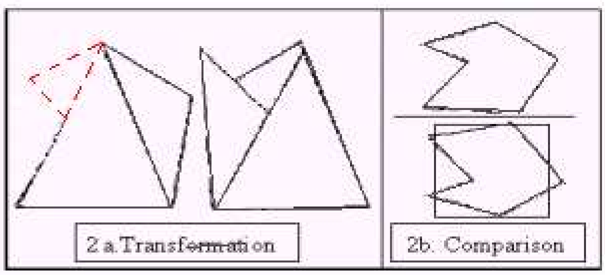

Figure 2. Examples of the use of T1 tools

All these constructions can be viewed as different representations of the concept of conservation of area. They are 'transparent' representations, reported by the literature, as prerequisites for pupils' understanding of the concept of area measurement. In terms of usability, the above tools can be used intuitively, since they simulate object manipulation activities. However, the way they have been implemented in the version of the software used, through a combination of menu commands and direct manipulation operations, could create confusion to the pupils.

T2. Tools for automatic measurements:. Two different tools are provided for pupils to automatically measure areas and lengths. These tools are presented under the 'Automatic Measurements' column, in Figure 1. In this type of measurement operation the use of standard units of length and of area are implied. By using these tools numerical representations of area measurement can be produced. These are 'opaque' representations and in order to be productive, justifications need to be developed by the pupils. More specifically, pupils have the chance to develop justifications of the equivalence of the variety of equivalent shapes they study, as well as to investigate the relationship between the area and the perimeter of these shapes. The simplicity of these tools makes them particularly easy to use. However, a limitation was that the measurements appear in a separate window, resulting in an unclear association of the displayed measurement to the measured object.

T3. Tools to dynamically represent equivalent areas: A number of different tools (presented under the 'Automatic Transformations' column, in Figure 1) are provided for the pupils to automatically transform areas already drawn, to equivalent ones. These equivalent areas are a *square*, a *rectangle with dimensions of ratio 1:2*, *a right-angled triangle with perpendicular sides of ratio 1:2*, and *classes of equivalent shapes* of the same form such as *rectangles*, *parallelograms and triangles* with common bases and equal altitudes (Figure 3). The above tools were designed to help pupils in studying the concept of conservation of area in a dynamic way.

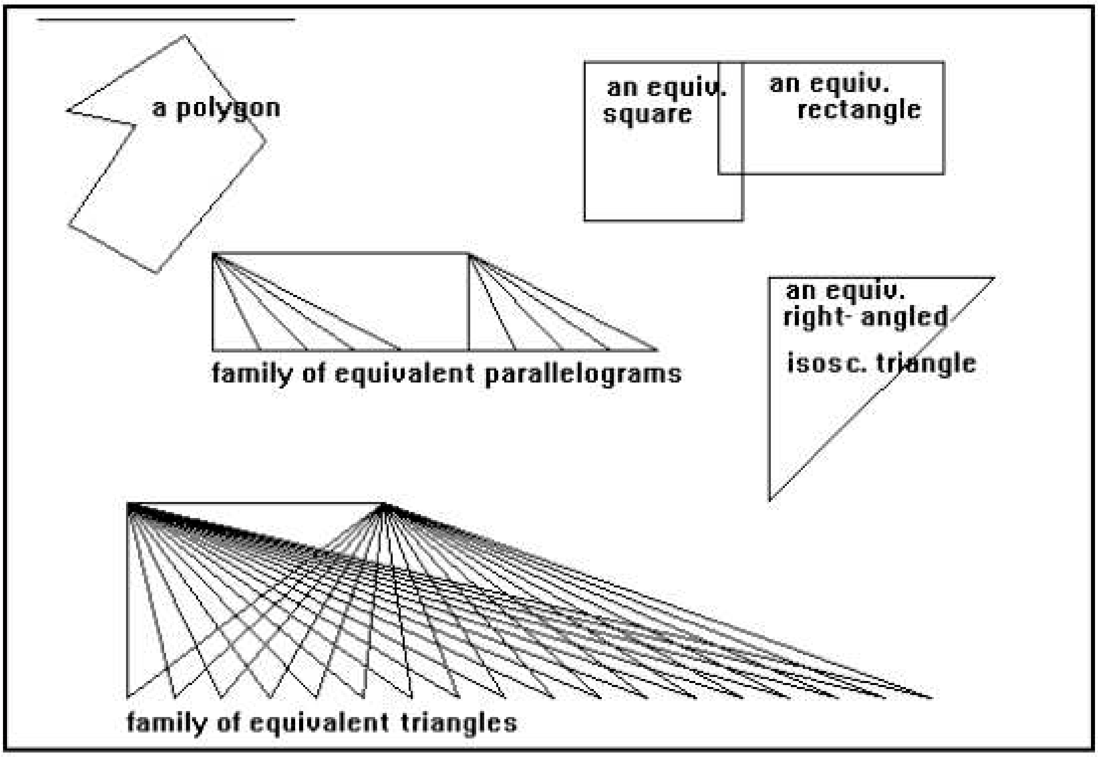

Figure 3. Examples of the use of T3 tools

Pupils can draw the base of a representative member for each of the above classes of shapes using the drawing tools of C.AR.ME Then, pupils can produce a number of equivalent shapes belonging to each class by using the appropriate tools. By altering these bases, a number of different classes of equivalent shapes of the same form can be produced.

By studying these equivalent shapes, pupils have the opportunity to explore different representations of the concept of conservation of area. These representations are 'opaque' but give the pupils the opportunity to study the concept of conservation of area in a dynamic way, to reflect on them and to form more abstract concepts. However, these representations need exploration as well as justifications by the pupils in order for the tasks to be meaningful. The role of dynamic representations in pupils' thinking is acknowledged by many researchers (Laborde, 1992; Dorfler, 1993; Mariotti, 1995). More specifically, by studying the plethora of the shapes included in the classes described above, pupils have the opportunity to explore the equal elements (bases and altitudes) of these shapes. This experimentation can help pupils to move gradually from visual to prepositional representations of the concept of conservation of area. The operation of these tools was based on a long sequence of menu commands. A number of usability problems have been discovered in this area in other studies of the C.AR.ME microworld (Kordaki & Avouris, 2001).

T4. Tools permitting use of spatial units and grids as representation systems: Pupils have the opportunity to measure an area by using a variety of spatial units or grids. These different units and grids, are offered to the pupils as tools for active area measurement. These tools are *a square, a rectangular, a pupils' unit* and *grids* respectively. Direct manipulation of these units, which can cover an area to be measured by the pupils, is an intuitive process. Two additional tools are available to create *personal units* and *grids*. Moreover, tools to perform *unit iteration* and for *counting the number of the units* needed to cover areas are also available. All the above tools are presented under the 'Measurement Tools' column, in Figure 1.

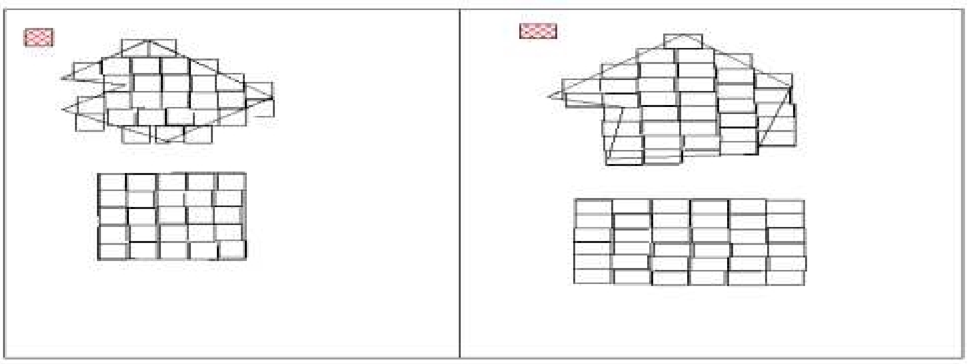

Figure 4. Examples of the use of T4 tools

The produced representations are 'transparent' and are reported by the literature as pre-requisite for pupils' understanding of area formulae. Examples of pupils' use of these tools are presented in figure 4. In terms of usability this approach is the most intuitive to implement, since it is based mostly on direct manipulation operations of the selected units.

THE CONTEXT OF THE STUDY

The learning experiment took place in the computer lab of a typical state secondary school in Patras, Greece, involving thirty (30) 14-year old pupils who participated in a problem-solving activity relating to the concepts of conservation of area and its measurement using the tools of C.AR.ME Regarding the gender of these pupils, ten pupils were girls and twenty were boys. The pupils worked individually, except for the familiarisation phase where they worked in pairs. The aim of this phase was to familiarize the pupils with the tools of the microworld and not to get them involved in the measurement process. The need for this phase emerged from the pilot study and took place before the pupils commenced the main study. The familiarization phase lasted about 2 hours for each pair. Overall, the pupils spent as much time as they needed to perform the given tasks. Each pupil spent on average about two hours per task. The researcher participated as an observer with minimum intervention. During this evaluation study two tasks were assigned to the pupils to be solved '*in any possible way'*. Firstly, the task of *transformation of a non-convex polygon to another shape with equal area*, and second, the task of *the comparison of a non-convex polygon to a square, not easily comparable by 'eye'*. The nature of these tasks allowed the pupils to develop multiple and different solution strategies expressing different pieces of knowledge they possessed about the learning concepts (Kordaki & Potari, 2002).

The data collected during this experiment were the automatically created log files containing the history of pupils' interactions with the tools, the screenshots of pupils drawings, audio recordings of verbal interactions between the pupils and the researcher and the field notes of her observations during the main study.

The data were organised in such a way that all individual pupils' solution strategies on each specific task were identified and reported. These strategies were analysed in terms of tools used.

RESULTS

Pupils used the tools of C.AR.ME to construct a variety of solution strategies for the given tasks during this experiment. Pupils' choice of tools was realized in the framework of these strategies. Based on this, pupils' alternative solution strategies to the given tasks are presented and reported first in this section, while the pupils' choice of tools in terms of their use is second. The framework of pupils' strategies as well as pupils' choice of tools are discussed in relation to: the diversity of the given tasks, the nature of the provided tools and the differences deriving from pupils' gender.

The framework of pupils' strategies

In an attempt to give evidence to the framework of pupils' strategies presented below are: the categories of pupils' alternative solution strategies to the given tasks, the pupils' strategies across categories, the most popular strategies as well as the pupils' involvement across categories and the order in which the pupils decided to construct them.

Categories of pupils' strategies: Pupils constructed 328 problem-solving strategies to complete both of the given tasks by using the provided tools of C.AR.ME or other methods. These strategies were classified into 28 categories with the criterion being the tools used by the pupils and are presented in Table I.

Table 1.

Categories of pupils' strategies in performing the task of transformation and of comparison in the context of C.AR.ME

Categories of pupils' transformation (C.T) and comparison (C.C) strategies in the context of C.AR.ME		
Categories performed (by using)	**C.T**	**C.C**
The 'eye'	C1	C1
The perimeter of the shapes	C2	C2
The tools for automatic transformations (T3)	**G1**	**G1**
The simulation of pupils' sensory-motor actions (T1)	**G2**	**G2**
The tools that support the operation of area measurement using spatial units (T4)	C6	C6
The simulation of pupils' sensory-motor actions in combination with the tools for automatic transformations (T1 & T3)	**G3**	**G3**
The tools that support the operation of area measurement using spatial units in combination with tools for automatic transformations (T3 & T4)	**G4**	C7
By enclosing the non-convex polygon in its minimum convex super set (E) in combination with the simulation of pupils sensory-motor actions (E&T1)	**G5**	-
By enclosing the non-convex polygon in its minimum convex super set in combination with the simulation of pupils sensory-motor actions and the tools for automatic transformations (E&T1&T3)	**G6**	-
By enclosing the non-convex polygon in a minimum convex super set in combination with the operation of area measurement using spatial units (E&T1&T4)	-	**G7**
By enclosing the non-convex polygon in a minimum convex super set in combination with the operation of area measurement using spatial units and the area formulae (E&T1&T4&AF)	**G8**	**G8**
The area formulae (AF)	C8	-
The tool for automatic area measurement in combination with area formulae (T2&AF)	C10	C10
The tool for automatic area measurement in combination with area formulae and the tools for automatic transformations (T2&T3)	**G9**	-
The tool for automatic area measurement (T2)	-	C3
The tool for automatic area measurement in combination with the simulation of pupils' sensory-motor actions (T1&T2)	-	C4
The tool for automatic area measurement in combination with the tools for automatic transformations (T2&T3)	-	C5
The area formulae in combination with the simulation of pupils' sensory-motor actions (T1&AF)	-	C9
The operation of area measurement using spatial units in combination with area formulae (T4&AF)	C11	-
	Sum = 14 cat.	Sum = 14 cat

In this way 14 categories were formed for each task. Twenty of these categories: G1, G2,…G9 and C1,..C11, are different as is shown in Table I. Of the above strategies, 154 were studied in relation to the concept of area measurement and were reported in Kordaki & Potari, (2002). These strategies were classified in eleven categories namely

C1, C2,…C11. The remaining 174 strategies are presented and discussed in Kordaki (2003) in relation to the concept of conservation of area. These 174 strategies were classified in nine categories (G1,…,G9).

Pupils' strategies across categories: The number of the pupils' transformation and comparison strategies across categories are presented in Table 2.

Table 2.

Pupils' strategies across categories

Pupils' strategies across transformation categories													
Categ	**G2**	**G1**	**C6**	**G3**	**G9**	**G4**	**C11**	**C1**	**C2**	**C8**	**C10**	**G5,G6,G8**	
Tools used	**T1**	**T3**	**T4**	**T1,T**	**T2,T3**	**T3,T4**	**T4 ,F**	**eye**	**per**	**AF**	**T2&F**	**T1,T3,T4,F, E**	
Girls	25	10	12	2	2	0	0	0	2	0	0	1	
Boys	42	18	28	8	4	1	5	1	2	1	1	4	
Pupils	67	28	40	10	6	1	5	1	4	1	1	5	
Pupils across transformation categories													
Girls	10	10	7	2	2	0	0	0	2	0	0	1	
Boys	20	18	12	6	3	1	2	1	2	1	1	4	
Pupils	30	28	19	8	5	1	2	1	4	1	1	5	
Pupils' strategies across comparison categories													
Cat.	**G2**	**C3**	**G1**	**C6**	**C4**	**G3**	**C5**	**C7**	**C9**	**C10**	**C1**	**C2**	**G7,G8**
Tools	**T1**	**T2**	**T3**	**T4**	**T1,T2**	**T1,T3**	**T2,T3**	**T3,T4**	**T1,F**	**T2,F**	**eye**	**per**	**T1,T4,F,E**
Girls	5	10	5	17	1	2	1	4	0	0	1	0	0
Boys	14	18	10	32	3	16	4	8	1	1	0	2	4
Pupils	19	28	15	49	4	18	5	12	1	1	1	2	4
Pupils across comparison categories													
Girls	3	8	4	8	1	2	1	3	0	0	1	0	0
Boys	11	15	6	17	3	14	4	6	1	1	0	2	3
Pupils	14	23	10	25	4	16	5	9	1	1	1	2	3

In total, 169 solution strategies were given by the 30 pupils (54 strategies given by girls and 115 by boys) to the task of transformation, using the tools of C.AR.ME (an average of 5.6 solutions per pupil/ 5.4 solutions per each girl and 5.75 solutions per each boy). The minimum value of pupils' solutions was 2 and the maximum was 9. More specifically, the minimum value of girls'/boys' solutions was 2 and the maximum was 6 for girls and 9 for boys. From these solutions 79.88 (%) involved the use of one tool, while 21.12 (%) involved combinations of the provided tools and combinations of these tools with other methods arising from the pupils' background (eg. area formulae).

Regarding the task of comparison, 159 solutions were given by the pupils above. 45 strategies were given by girls and 115 by boys, an average of 5.3 solutions per pupil (4.6 solutions per each girl and 5.65 solutions per each boy). The minimum value of pupils' solution strategies was 3 and the maximum 10. The minimum value of girls'/boys' solutions was 2/3 correspondingly while the maximum was 7 for girls and 10 for boys. From these solutions 69.81 (%) involved the use of one tool, while 30.18 (%) involved combinations of the provided tools and combinations of these tools and other techniques.

Most popular categories of strategies: The top strategies are shown in Table 2. In this table one can see that the most popular strategies in both tasks are those included in the categories G1, G2, C6 and G3 (performed using the tools T3, T1, T4 and T1&T3, respectively) while for the comparison task additional strategies are those included in the categories C3, C7 (performed using the tools T2 and the combination of tools T3&T4, respectively). These top strategies mainly involved the use of one tool. The fact that these two additional categories were more popular in the comparison task probably indicates pupils' familiarization with the related tools during the transformation task that they first performed.

The average number of alternative solutions given, using each strategy is of interest. Strategies that have been re-applied present versatility. So, in Table 2 it can be seen that the maximum value of this index is associated with strategies included in the transformation category G2 and in the comparison category C6 (about 2 solution strategies per pupil), while the rest are in the range [1..2]. This indicates that some strategies invited the user to re-apply them in alternative ways. For instance strategy G2 involved use of tools (T1) which simulate pupils' sensory-motor actions to perform area transformations. Moreover, strategy C6 involved the use of grids and spatial units of various shapes (tools T4). The construction of these strategies was based on tools that were designed in such a way as to support representations that permit the expression of pupils' intuitive knowledge regarding both tasks.

Pupils across categories: An interesting feature is the number of pupils who constructed a specific solution strategy. The number of pupils who performed strategies included in each category in both tasks is also presented in table 2. Most pupils were involved in the construction of strategies included in the transformation categories G2, G1 and C6 (using tools T1, T3 and T4, respectively) as well as in the comparison categories C6, C3 (using tools T4 and T2, respectively). So, almost all pupils used the tools T1, T3 and T4 while two out of three used the T2 tool.

An interesting finding relates to the plethora of strategies invented by the pupils, combining the available tools. Half of the pupils were involved in the construction of strategies included in the comparison categories G2 and G3, using the tools in the T1 group in combination and the tools in the T1 group in combination with the tools in the T3 group respectively. One out of three pupils combined the tools for automatic transformations with the use of spatial units (strategy C7, tools T3, T4). Representations corresponding to strategies C8, C9 and C10 were performed by fewer pupils, as these emphasised the use of area formulae that were not explicitly supported by any tool in this environment. Representations such as those described in strategies G4, G5, G6, G7, and G8 were also performed by fewer pupils, as these strategies are more advanced, demanding the use of a combination of tools, the use of area formulae as well as a more complex view of the shape under study. Representations such as those described in strategy C2 express pupils' misconceptions about the concept of area and were performed by few pupils namely the strategies included in categories C5 and G9 (using the tools T2 in combination with T3).

The order of strategies' performance: Concerning the order in which the strategies were applied, two indices were defined in both tasks: the "Pupils' First Strategy Index (PFSI)", assigned to the strategy that was used first by a specific pupil, and the "Pupils' Last Strategy Index (PLSI)", assigned to the last strategy. The distribution of these indices in our population of learners is shown in Table 3. In this table the distribution of the above indices both for girls and boys is also shown.

Table 3.

The order of strategies' performance

Pupils' first transformation strategies (PFSI)											
Categ.	**G2**	**G1**	**C6**	**G3**	**G9**	**G4**	**C11**	**G5,G6,G8**			
Tools	**T1**	**T3**	**T4**	**T1, T3**	**T2,T3**	**T3,T4**	**T4 ,F**	**T1,T3,T4F, E**			
Girls	3	5	1	0	1	0	0	0			
Boys	5	11	2	0	1	0	0	0			
Pupils	8	17	3	0	2	0	0	0			
Pupils' last transformation strategies (PLSI)											
Girls	3	0	3	1	1	0	0	1			
Boys	6	1	6	4	0	0	0	3			
Pupils	9	1	9	5	1	0	0	4			
Pupils' first comparison strategies (PFSI)											
Categ.	**G2**	**C3**	**G1**	**C6**	**C4**	**G3**	**C5**	**C7**	**C9**	**C10**	**G7, G8**
Tools	**T1**	**T2**	**T3**	**T4**	**T1,T2**	**T1,T3**	**T2,T3**	**T3,T4**	**T1,F**	**T2,F**	**T1,T4,F,E**
Girls	0	6	0	3	0	0	0	0	0	0	0
Boys	1	13	1	4	0	0	0	0	0	0	0
Pupils	1	9	1	7	0	0	0	0	0	0	0
Pupils' last comparison strategies (PLSI)											
Girls	1	1	3	4	0	0	0	1	0	0	0
Boys	3	0	0	2	1	0	2	4	0	0	3
Pupils	4	1	3	6	1	0	2	5	0	0	3

From this table one can deduce that for the first strategy and for both tasks, there is a bias towards the simplest automatically performed solutions to the given problems (categories G1, and C3), in terms of cognitive load and tool usability. Despite this fact, pupils' last strategies in both tasks, were distributed more evenly among more advanced problem-solving strategies where solution plans and combination of tools were used. Gender differences did not seem to affect the order of the strategies performed.

Pupils' choice of tools

An alternative approach in studying the interaction of pupils with this environment involves analysis of the tools used in the construction of pupils' problem-solving strategies. As shown in Table 1, each strategy involved one or more tools. An interesting feature is the number of pupils who used each tool to apply a specific solution strategy in both tasks. Moreover, the number of specific strategies performed by the learners using each tool is of interest. In this section pupils' choice of tools in both tasks is demonstrated in two ways a) by presenting the tools used across pupils' and b) by presenting the frequency of use of each specific tool by the pupils during this experiment. Pupils' choice of tools is also presented in relation to: the diversity of tasks, the differences deriving from the pupils' gender as well as to the nature of the provided tools.

a) Distribution of tools used across pupils

The tools used in relation to the number of pupils who used each tool is presented in Table 4. This table also presents the number of girls and of boys who used each tool.

The first column of this table represents each group of tools T1, T2, T3, T4, where some tools of each group were used in combination, while T1* denotes exclusive use of one tool of this group. Moreover, (T1,T3) represents the use of a combination of tools included in T1 and T3, similarly (T3,T4) means the use of a combination of tools included in T3 and T4. In addition, T1all, T2all, T3all, T4all represents the basic groups of the provided tools used in any combination in each task. In each cell of the second column the number of pupils (n) who used the corresponding tools included in each cell of the first column is presented. The number both of girls (n1) and of boys (n2) who used the previously mentioned tools is presented in the fourth and sixth column of this table, respectively. The third column of this table presents the percentage of pupils (n/30) who used the respective tools while the fifth and the last column presents the percentage of girls (n1/10) and of boys (n2/20) respectively.

Table 4.

Distribution of the use of tools across pupils

Tools used/task	**Pupils**		**Girls**		**Boys**	
Transformation task performed by using..	**Number (n)**	**% n/30**	**Number (n1)**	**% n1/10**	**Number (n2)**	**% n2/20**
T1*	19	63,33	8	80	11	55
T3	28	93,33	10	100	18	90
T4	19	63,33	7	70	12	60
T1,T3	8	26,66	2	20	6	30
T1	23	76,66	5	50	18	90
T2	5	16,66	2	20	3	15
T1all	26	86,66	9	90	19	95
T2all	5	16,66	2	20	3	15
T3all	28	93,33	10	100	18	90
T4all	19	63,33	7	70	12	60
Comparison task performed by using..						
T1	14	46,66	3	30	11	55
T2	23	76,66	8	80	15	75
T3	10	33,33	4	40	6	30
T4	25	83,33	8	80	17	85
T1,T3	16	53,33	2	20	14	70
T3,T4	9	30	3	30	6	30
T1all	21	70	4	40	17	85
T2all	23	76,66	8	80	15	75
T3all	24	80	6	60	18	90
T4all	29	96,66	10	100	19	95

Tasks and pupils' choice of tools: In the transformation task, T3 and T1 in isolation as well as in combination with the other tools were used by more pupils whereas in the comparison task they were used less (Table 3, column 3). In addition, T2 and T4 in isolation as well as in combination with the other tools were used by more pupils in the comparison task whereas in the transformation task they were used less (Table 3, column 3). Moreover, the majority of pupils used the T3 tools to perform the transformation task while the majority of pupils used the T2 tool to perform the task of comparison. This fact indicates that pupils preferred tools that produce automatic solutions to given tasks.

Gender and pupils' choice of tools: Girls' and boys' choices of tools in both tasks followed the same pattern described in the previous paragraph. However, more girls than boys preferred the use of tools T1*, T2, T3 and T4 in both tasks. Combinations of tools (T1 tools and T1 combined with T3) were used by more boys than girls in both tasks.

The nature of tools and pupils' choice of tools: The basic groups of the provided tools were used in isolation by a significant percentage of pupils as shown in Table 4. However, a limited percentage of pupils used these tools in combination. More specifically, the combination of tools included in the T1 group, the combination of tools included in the T1 and T3 groups as well as the combination of tools included in the T3 and T4 groups were not widely used by the pupils. This fact indicates that the usability problems of these tools regarding their inter-operation, restrained these pupils from using them in combination, as extra cognitive effort is needed by the pupils to construct strategies for these combinations of tools.

b) Frequency distribution of use of tools across pupils

As each tool could be used more than once by each pupil during this experiment, the popularity of tools in terms of their frequency of usage is of interest. The distribution of frequency of tool usage in both tasks across pupils is presented in Table 5.

In the first column of this table, the tools used in the most popular categories of strategies in both tasks as well as the provided basic groups of tools used in any combination are presented. Here, the symbols used have the same meaning as those used in the first column of Table 4. In each cell of the second column of Table 5, the number of strategies (n) performed using the tools mentioned above is presented. The number of strategies performed both by girls (n1) and by boys (n2) who participated in this experiment is presented in the fourth and sixth columns of this table respectively.

The third column of this table, presents the percentage of strategies performed by pupils using these tools correspondingly while the fifth and the last column present the percentage of strategies performed by girls and boys, respectively.

Table 5.

Frequency distribution of the use of tools across pupils

Tools used/ task	**Strategies performed by**					
	pupils		**girls**		**boys**	
Transformation task performed by using..	**number (n)**	**% n/167**	**number (n1)**	**% n1/54**	**number (n2)**	**(%) n2/113**
T1*	48	29	22	41	26	23
T3	28	17	10	18	18	16
T4	40	24	12	22	28	25
T1,T3	10	6	2	4	8	7
T1	19	12	3	6	16	14
Any combination of tools	22	12	5	9	17	15
Total strategies	167	100	54	100	113	100
Comparison task performed by using..	**number (n)**	**% n/158**	**number (n1)**	**% n1/47**	**number (n2)**	**(%) n2/111**
T1	19	12	5	11,5	14	12
T2	28	18	10	21	18	16
T3	15	9	5	11,5	10	9
T4	49	31	17	36	32	29
T1,T3	18	11	2	4	16	14
T3,T4	12	8	4	8	8	7
Any combination of tools	17	11	4	8	13	13
Total strategies	158	100	47	100	111	100

Tasks and frequency distribution of use of tools: Here, as well, a significant number of strategies performed by pupils related to the use of tools included in groups T1 and T2 regarding the tasks of transformation and of comparison correspondingly. Moreover, the number of strategies performed using T4 tools is significant in both tasks. Despite the fact that the number of strategies performed by using the provided tools in combination can be viewed as limited in the task of transformation, this number increases in the task of comparison. It indicates that pupils performed better as they used the provided tools repeatedly.

Gender and frequency distribution of use of tools: Girls and boys performed a significant number of strategies by using the provided tools in isolation in both tasks.

However, boys performed more strategies involving a combination of tools than girls in both tasks as well.

The nature of tools and frequency distribution of their use: A significant percentage of strategies performed by using the basic groups of the provided tools in isolation (simple use of tools) as shown in Table 5. Despite this fact, a limited percentage of strategies were performed by using a combination of tools. These strategies refer to the use of a combination of tools included in the group T1, combinations of tools included in T1 and T3 as well as combinations of tools included in T3 and T4. This fact indicates that the usability problems of these tools appearing in their inter-operation prevented pupils from performing the associated strategies.

DISCUSSION

The results of the present investigation demonstrate that pupils' choice of tools provided by an open problem-solving environment (the C.AR.ME microworld) is related to the basic elements of the learning context, namely, the given tasks, the pupils' gender and the nature of the provided tools in terms of both their cognitive transparency and their usability. Pupils' choice of tools is discussed below in relation to the essential elements of the whole learning context mentioned above.

Tasks and pupils' choice of tools: The nature of the tasks involved in asking pupils to solve them 'in any possible way' in relation to the availability of a variety of different tools encouraged pupils to use these tools in alternative ways and to construct a diversity of solution strategies. More specifically, twenty different categories of strategies were performed by the pupils using the tools in this computer environment. During the design of C.AR.ME the assumption was implicitly made that pupils would solve the given tasks using four alternative approaches imposed by the four groups of tools provided. However, the experiment revealed that the pupils invented more complex problem solving strategies, often involving a combination of tools. This mismatch between the environment designer's expectations and the usage observed during experimentation, which was discussed in Kordaki & Avouris, (2002), suggests that such complex environments should incorporate flexible and robust tools, capable of inter-operating in many alternative ways, since it is not possible to foresee all possible uses of the tools in such open environments.

The most popular strategies were performed by using the provided groups of tools in isolation. Combinations of tools were used to produce more advanced problem-solving strategies. The most dominant strategies, constructed by most pupils were based on a) the use of automatic performance of both tasks (strategies C3 and G1, performed using tools T2 and T3 respectively) and b) the use of spatial units and/or grids to measure areas (strategy C6, T4 tools). T4 helps in the construction of 'cognitively transparent' representations as it is spatial and visual and, as confirmed by the literature, matches the pupils' typical cognitive processes in solving area measurement problems.

Pupils' first strategies in both tasks rely on the automatic performance of these tasks. As shown in Table 2, pupils' first transformation strategies mostly involved the use of tools for automatic transformations (T3 tools). In addition, pupils' first comparison strategies mostly involved the use of tools for automatic area measurement (T2 tools). These strategies, based on 'opaque' representations which are fast and easily performed as automatic operations, provide numerical feedback easily interpreted by the pupils. Pupils' last strategies in both tasks, were more advanced, as they demanded the construction of solution plans and the use of a combination of tools.

Moreover, the diversity of tasks invited pupils to use different tools in performing the most popular strategies for each task. More specifically, pupils mainly used the tools for automatic transformations (T3 tools) and the tools that simulate pupils' sensory-motor actions to manipulate areas without the use of numbers (T1 tools) during the task of transformation. Despite the fact that the majority of pupils used the T3 tools during this task, the majority of strategies were performed using the T1 tools. Pupils also mainly used the tool for automatic area measurement (T2 tools) and the tools for area measurement using spatial units and grids (T4 tools) to perform the task of comparison. The majority of pupils and of solution strategies given to this task were performed using the T2 tools. In both tasks pupils preferred to use the tools T2 and T3 which acknowledge the automatic solution of these tasks by the computer, as well as the tools T1 and T4 which gave them the opportunity to express their intuitive knowledge about area transformations or area measurement Moreover, all pupils performed more solution strategies during the second task (the task of comparison). Pupils also used the provided tools in combination in more strategies when they were involved in the second task. These facts show that pupils mastered the use of the provided tools as they progressed during the task performances.

Gender differences and pupils' choice of tools: All pupils were actively involved in using the tools of C.AR.ME by performing at least 2 solution strategies per task while this number increased during the performance of the task of comparison. However, the average solution strategies performed by girls in both tasks was slightly less than the average solution strategies performed by boys. Almost all pupils also used the provided tools T1, T3 and T4 in isolation while two out of three used the tools T2. Gender differences were observed in using the provided tools in combination in both tasks. More specifically, more boys than girls used the combination of the tools included in group T1 as well as the combination of the tools included in the groups T1 and T3.

Moreover, more strategies using a combination of tools, including also the previously mentioned ones, were performed by more boys than girls in both tasks.

Nature of tools and pupils' choice of tools: Pupils seemed to prefer the use of T3 and T2 tools to perform the task of transformation and of comparison, respectively despite their cognitive opaqueness and their problems of usability. These tools allowed the pupils to rely on the computer automatically performing the given tasks. T1 and T2 tools were also widely used in isolation, as these tools enabled the pupils to express their intuitive knowledge about the learning concepts. However, the percentages of pupils and strategies performed in using the provided tools in isolation are small in comparison to the corresponding percentages regarding the use of these tools in combination. The most significant difficulties involved the combination of tools included in the T1 group as well as in the combination of tools included in the T1 and T3 groups. These tools have serious usability problems that seem to affect most pupils in using them in combination. Girls also seemed to face more difficulties than boys in coping with these usability problems. Recapitulating, pupils seemed to face difficulties in using all the provided tools in inter-operation. In my view, these difficulties are due to the fact that all tools were designed to be used in isolation as well as to the fact that a combination of tools was mainly used in the construction of more advanced solution strategies.

CONCLUSIONS

This study demonstrates that pupils used, in un-anticipated ways, all the provided tools separately as well as in combination and constructed a variety of representations of conservation of area and its measurement throughout their solution strategies. Pupils also constructed representations based on their previous knowledge despite the fact that these representations are not explicitly supported by the provided tools. In conclusion, the design of tools included in open problem solving environments, should be done in such a way that provisions are made for un-anticipated use and for their inter-operability. At the same time, we must bear in mind that certain tools should be designed so as to allow pupils to express their previous knowledge.

This study also shows that pupils preferred the tools that helped them in automatically solving the given tasks producing quick representations despite their 'opaqueness'. Moreover, the tools that helped in the construction of transparent representations were chosen by most pupils. The nature of tasks asking pupils to solve them 'in any possible way' encouraged most pupils to use all the provided tools. In addition, the diversity of tasks affected the pupils' choice of tools.

Girls and boys also differed in their choice of tools. More specifically, girls mainly used the provided tools in isolation while boys used these tools in combination more successfully than girls. Despite this fact, the variety of the provided tools gave both, girls and boys the opportunity to express their knowledge about the learning subject constructing more than two solution strategies to the given tasks.

The usability of the tools affected the way they are incorporated in problem solving, at times not matching the cognitive complexity of the underlying theoretical approach. It is therefore important to incorporate usability evaluation studies in design, in order to ensure that an extra cognitive effort is not imposed on the pupils due to usability issues.

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