# Use of UML for Modelling the Holistic Geometry in Primary Education

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***Abstract***

The paper deals with transformations of the holistic conception of primary geometric education in the context of mixed reality. This concept is aimed at the analysis of education implying a simultaneous insight into the geometric education from the viewpoint of philosophy, mathematics, technology, pedagogics, psychology, linguistics and aesthetics. The main attention and analyses are addressed to technological peculiarities of the holistic conception framed by the shape of situated learning. Due to the complexity of learning environment, UML (Unified Modelling Language) is chosen for the description of the education process. The process of developing the model is illustrated by using different types of UML diagrams: Use case, Class and Activity. Finally, peculiarities of the object-oriented approach applied in modelling the situated geometry learning environment are discussed.

***Keywords***

*UML; Geometric Education; Learning Design; Object-Oriented Approach; Situated Learning; Primary Education; Curriculum Integration*

## Introduction

Holistic education is a philosophy of education based on the system as a whole which determines how its parts behave. A holistic way of thinking tries to encompass and integrate multiple layers of information about the education process and education object.

In pedagogy, holistic education is associated with an integrated curricula approach. The concept "integrated" means that any subject is blended into the whole educational process, incorporated as part of a larger picture, driven by the goal of equality. All learners feel that their ideas, contributions, and work are valued , and that they are able to succeed (Silver, Strong & Perini, 2000).

If we consider integration as part of the organisation of the education process, we should point out the main components: the integration of experiences, social integration, integration of knowledge, integration as a curriculum design (Beane, 1997). In this sense, integration means incorporation of new experience of a learner into already acquired schemes of meaning, harmonisation of private and social interests and flexibility to deal with problems as broadly as they are in real life and to use a wide range of knowledge to address them.

If we discuss integration with regard to participants of the education process, the integrated learning is considered as an approach dealing with curricula, instruction, and assessment designed to help teachers and schools fusing multiple intelligences and learning styles in a meaningful and practical way (Silver, Strong & Perini, 2000). Thus, the connection between education phenomena and psychological learners' particularities is emphasized.

While discussing the curriculum integration, three dimensions should be taken into account: cognitive processes of individuals, social processes inside a community, and interaction between individuals and community. At present, it is important to add information technologies as well. Considering that the conception of holistic education became more complicated, we should bring the integration of learning aids up-to-date as well.

Blended teaching and learning mean harmonisation of different learning environments in an integrated curriculum. It combines traditional face-to-face classroom methods with some modern computer-mediated activities and makes true integration of aids and appliances.

Mixed reality technology in education can be considered as the next generation of blended learning environment that is realistic, authentic, engaging and extremely fun (Yusoff, Zaman & Ahmad, 2010). Such learning environment integration comes through the permanent interaction between real and virtual environments. In a mixed reality in education, the aids are integrated in both organisation and participation processes, and preferences of aid applications depend on the context.

A virtual reality can simulate phenomena in the real world and display some concepts and experimental procedures that are difficult to present and observe (Tarng, Tsai, Lin & Shiu, 2009). Generally speaking, the situated learning can be described as a learning that takes place in the same context in which it is applied. Simulations and virtual reality provide the basis for one form of situated learning by modelling specific aspects of real-world complex systems, allowing learners to experiment with the system either by manipulating parameters or participating inside the system and observing outcomes (Yusoff, Zaman & Ahmad, 2010). On the other hand, combining virtual reality with exploration of real-world objects in the situated learning environment can enrich learner's experience by sensorimotor aspects. Suitability of the mixed reality to investigate real-life objects, based on additional virtual experience, can be especially beneficial in developing the understanding of spatial relations.

Therefore, the mixed reality technology in education can manifest via application of real and virtual tools oriented to the education context. In this case, a holistic viewpoint means orientation to individual needs and individual cognitive processes. His/her demand to communicate can be strengthened with a richer, pleasant, and diverse experience.

A broad extent of the concept of curriculum integration reflects the contemporary attitude to education. Also, it becomes even more difficult to apply in the educational practice. The problem lies within the design of the holistic education, encapsulating descriptions of real and virtual learning environments as well as their mutual interaction. Intuitive understanding of the integration topic is insufficient for a complicated phenomenon of education.

In this context, modelling of the holistic geometric education in a primary school means investigation of the chosen domain, visual description of an up-to-date education process and interpretation of the constructed schema in the mixed reality context.

The aim of this paper is to explore the particularities of modelling of situated learning through holistic geometric education in a primary school stage.

The efficiency of the presented theoretical model on formation of geometric images at a primary school stage is empirically validated only in the context of manual geometric craft activities (Grabauskiene, 2005). To verify whether the model is suitable to achieve holistic geometric education goals, at a first mixed learning environment, which matches the geometric image formation model, should be developed.

The research object of this paper is learning design. Research focus addresses both the e-learning environment and face-to-face environment, and the relationship between them as well.

The main questions answers to which are sought in this paper:

- How does the context of mixed reality transform the conception of geometric education?
- How the UML (Unified Modelling Language) can be applied to modelling of situated learning environment?
- How does the object-oriented (O-O) approach stand up for learning design?

Modelling of geometric education is chosen as research method. The e-learning environment model is designed by applying the UML Use case, Class and Activity diagrams. To outline the face-to-face model, the UML Use case, Class and Activity diagrams are used as well. Interaction between the e-learning and face-to-face learning environments is displayed by using the O-O approach.

## Essence of the Model of Formation of Geometric Images at Primary School Stage

### *The Model of Formation of Geometric Images at Primary School Stage: an Overview*

The theoretical substantiated model (Fig. 1) of formation of geometric images at a primary school stage (Grabauskiene. 2005) is based on the structure of geometric images; specifics of geometric image expression; the conception of geometric education basics as well as the analysis of worldwide experience acquired in the area of primary geometric education.

The conception of geometric image formation refers to the formation of topological, projection-based and metrical images and training aiming at the development of schoolchildren's skills in expressing geometric images (Grabauskiene, 2005).

Topological images include a conception of the form (visual and touch properties). Projection-based images cover a universal conception (conception of key projections; combination of different approaches; conception of transformations). Metrical images cover a conception of size (combination of metrical and non-metrical images; conception of segmentation into n-dimensional pieces).

Verbal and visual expressions of geometric images are important for exploration and interpretation of geometric discoveries in the investigative activity. The manual or virtual modelling of geometric shapes can be treated as an example of geometric images expression. The functioning of the model should be related to the dialectical development of geometric knowledge, skills and capabilities of a schoolchild (Fig. 1).

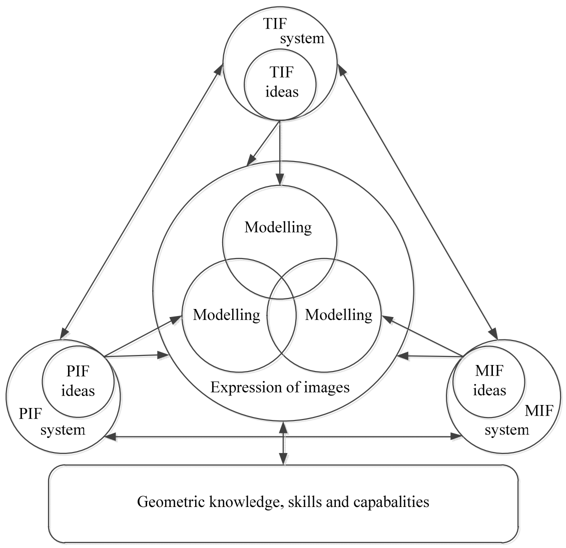


FIG. 1. MODEL OF FORMATION OF GEOMETRIC IMAGES AT A PRIMARY SCHOOL STAGE

(ABBREVIATIONS: T - TOPOLOGICAL; P – PROJECTION-BASED; M – METRICAL; IF – FORMATION OF IMAGES)

The essence of the geometric image formation model is harmonisation of

- the structure of geometric image formation,
- the formation of various geometric images (descriptive, constructive, visual, and dynamic geometry),
- the modes of geometric image expression.

Therefore the formation of geometric images based on this model should be placed as situated learning.

From the intellectual standpoint, the craft activities are a very rich source of mathematical or scientific ideas and images (Hendrich & Eisenberg, 2005) and any activity of geometric construction is situated cognition by itself.

### *Analysis of the Model of Formation of Geometric Images in the Mixed Reality Context*

The essential components of the geometric image formation model at a primary school stage are invariants in a variety of real and virtual means applications. Using the reality and virtuality of geometric education we can support different activities (Fig. 2):

- gathering of experience relevant to topological, projection-based, and metrical image formation;
- communication using differently expressed geometric images.

Geometric image formation in the real education environment is distinguished by sensorimotor proficiency. The virtual environment allows some time to gain a notably large experience and additionally provides rich communication possibilities: the community of wiki users can work together sharing digital artefact (Kimmerle, Moskaliuk & Cress, 2011).

Computationally-enriched crafts are activities that blend the advantages of computational media with the affective, social, and cognitive affordances of children's craft (Hendrich & Eisenberg, 2005). The advent of computation enhances the expressive capabilities of the existing materials (Blauvelt, Wrensch & Eisenberg, 1999). It is supposed that applying the geometric image formation model in the mixed reality context, the synergetic harmony of virtual and real education environments can emerge.

However, the advantages in the mixed reality of holistic education are not dissociated from the implementation problems. A modern world is not linear or one dimensional and static (Haberman & Ragonis, 2010).

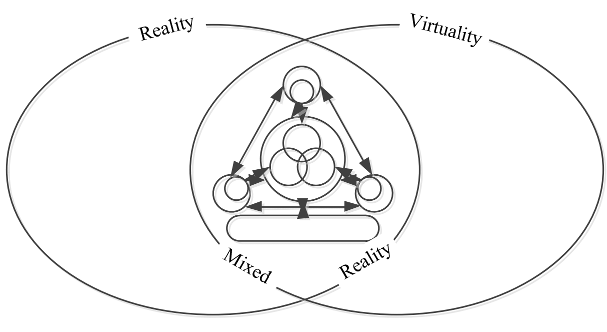


FIG. 2. THE SCOPE OF APPLICATION OF THE GEOMETRIC IMAGE FORMATION MODEL

If the application of the geometric image formation model just to the real or virtual education environment can be equated to one-dimensional process, then the mixed reality in this case embodies two-dimensional process: in each education activity of the education situation one can spot more or less of the reality and virtuality attributes. Mainly a particular situated learning process can be represented as a broken curve, making out of points represented in the reality-virtuality coordinate system. The curve properties provide an opportunity to change the real-virtual world relationship at any moment subject to a concrete education situation. Only in this sense, the situated learning modelling is complicated in the mixed reality context.

It should be noted that ideas of the geometrical image formation model can be applied at any point on such a curve. Fig. 2 shows the spread of application of the model reflects the purpose of each such point from the situated learning curve: to create optimal conditions for geometric image formation.

The analysis of the model of formation of geometric images made in a mixed reality context displays that:

- The mixed reality education environment is complicated. A model of formation of geometric images should consider mixed reality-virtuality dimensions.
- Modelling of two separated real and virtual education environments is interference for description of holistic education process.
- In order to simplify the situated learning model and consider two dimensions of situated learning process in the holistic education model, the O-O paradigm should be used.

## Design Specifications of the Learning Environment

### *Substantiation of UML Application in Holistic Geometrical Education Design*

The primary factor that influences the effectiveness of learning is not the availability of technology, but the pedagogical design (Wang, 2009). The pedagogical design includes selecting what to teach, how to teach it, what to evaluate and how to combine all of these parts. A systematic development of learning materials (including the use of technology and multimedia) is aimed at making the learning as effective and efficient as possible (Mohanna & Waters, 2008). Since the adaptability of the model is determined by its validation and visualisation properties, to realise the practical geometrical image formation model, the choice of pedagogical design form is the most important.

Various modelling tools can be used for the design of educational environments.

For example, $E^2$ML can be used for visualizing intermediate and final results of the design. Modelling is proceeded by making drawings (Botturi, 2006):

- Action diagrams (representing the educational environment as a structured system of activities).
- A diagram of the dependencies (the idea is that each educational environment has a deep structure connecting its activities in a meaningful way).
- The flow of activities (overview of the flow of educational activities during the course of a time span).

EML is used to formally describe abstract learning scenarios, ensuring in this way, reuse, exchange, and interoperability (Laforcade, 2007):

- A concrete educational problem is analysed and a narrative didactic scenario is created.
- Due to the accuracy, the scenario is redrawing in the UML Activity diagram.
- On the basis of the Activity diagram, XML document is created.

UML4LD is a specific language and tool for translating abstract scenarios (specified with EML) to domain-specific (human-readable) scenarios (Laforcade, 2007):

- Based on the formal EML scenario, the elements of the UML model are created.
- Using the elements of the UML model, the Activity diagram is created automatically.

UML is a standard language for specifying, visualizing, constructing, and documenting the artefacts of software systems for object-oriented analyses and design (Ansari, Mohamed & Syed, 2011; Ansari, 2010; Jakimi & Elkoutbi, 2009; Popandreeva, 2009). Two main features have been used:

- Performing of analysis (the Use case model).

- Creation of design (e.g. Class diagram, Sequence diagram, Activity diagram…).

UML is a language for visual modelling; it adopts a view of the real-world system and describes it in the form of pictures and notation (Ansari, 2010).

The methodology of system development (structural, behavioural, interactional (Ansari, Mohamed & Syed, 2011) and language approach ("interpretative" or "constructive" approach (Ouraiba, Choquet & Cottier, 2011) displays general opportunities of a design: the learning environment can be understandable as a result of synthesis of various viewpoints. Opportunity of such a synthesis can be illustrated by suggestions of constructive modelling, for example, application of a business process and concept modelling to represent systems in the platform independent manner (Nikiforova, 2010), combining several scenarios (Jakimi & Elkoutbi, 2009).

When choosing a modelling language its suitability for teachers should be examined (Ouraiba, Choquet & Cottier, 2011; Laforcade, 2007):

- Possibility to participate in designing an educational environment.
- Possibility to understand, adapt and reengineer an abstract model.
- Possibility to simplify the modelling language.

In summary, considering the complexity of the designed learning environment, the most suitable language for modelling of holistic primary geometrical education in the mixed reality context is an UML. Whose suitability is determined by: visual form, O-O nature, variety of separate views to the designed system, possibility to model a situated learning environment in an abstract, compact as well as informative way due to the O-O. It looks like because of the mentioned features and a generalised learning environment description, when presented in the form of some the UML diagrams (Use case, Class, Activity), can be easier understood by teachers.

### *Modelling of the Situated Learning Approach*

In view of the situated learning, geometrical knowledge needs to be presented in an authentic context, capable of providing student with a personal exploration experience and interactive interchange of knowledge. Thus, when designing the process of situated learning, accents are put on the education methods.

A learning method is the expedient approach system of learning activities. The extent of the learning method concept and structural relationships based on the O-O viewpoint are conveniently represented by a logical learning method model (Fig. 3).

The O-O paradigm is suitable for that case because it enables us to represent different relations between classes (Haberman & Ragonis, 2010), for example, inheritance.

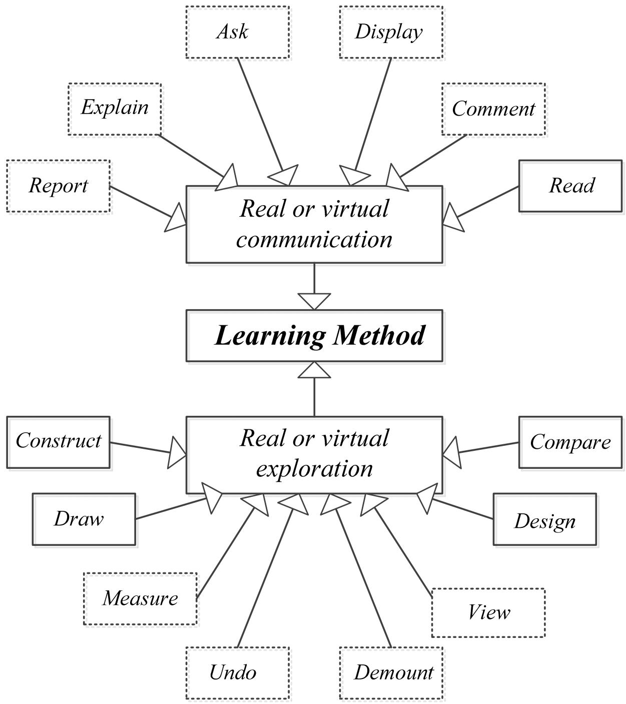


FIG. 3. CLASS DIAGRAM FOR THE SITUATED LEARNING METHOD CLASS

The real or virtual exploration and communication methods are important for holistic geometric education in a primary school stage (Fig. 1).

While modelling the learning method, constraints were placed on 6 communication and 8 research activities. It is worth noting that all of these activities are suitable for learning in the real environment. All operations described by interfaces, on the grounds of O-O ideas are abstract, therefore suitable for denoting both real and virtual activities. A dashed line was chosen to mark interfaces which are most relevant to the virtual environment. It should be noted that the above mentioned real-virtual interfaces partitioning reflects the importance of manual activities for the younger school age years as well as consideration of the psychological peculiarities of children of this. The chosen set of interfaces can be easily changed in the future.

In summary, the situated learning process in general can be characterised by the hierarchy of inheritance: activity interface → activity → learning method. The activity interface can be treated as an abstract activity for elaboration of the learning method.

***Diagram of the UML Use Case for the Situated Geometry Learning Environment***

The Use case is intended for the elaboration of real choices of the modelled system. Therefore the Use Case titles shown in Fig. 4 reflect the variants that describe the learning environment's functionality. Polymorphism, typical of the O-O viewpoint, allows interpreting the depicted functionality in the reality-virtuality coordinate system. Hence, the same diagram is appropriate to define the whole mixed reality educational environment.

Agent *Visitor* (who covers the roles of a pupil, teacher, and administrator) expresses the variety of participants in the learning environment. A simplified model is achieved in this way, concisely expressing the idea: *Visitor* can choose an activity adequate to his status. Looking from the education attitude witch means an active collaboration of educational process participants with the view of educational goals.

Primary school pupils learn geometric shapes (2- and 3-dimensional), thus the Use case *Figure* names the geometric shape selected for investigation.

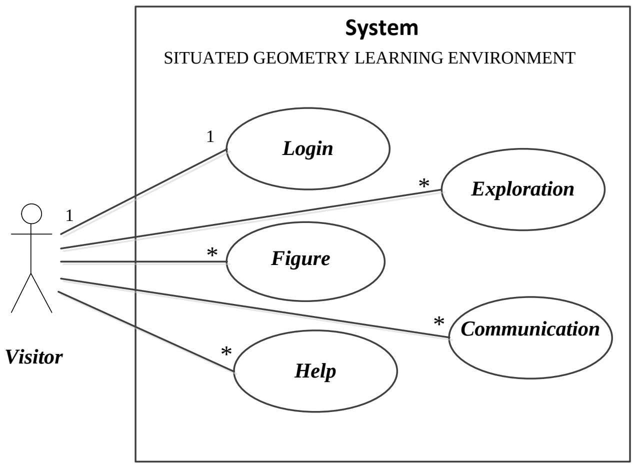


FIG. 4. USE CASE DIAGRAM FOR THE SITUATED GEOMETRY LEARNING ENVIRONMENT

Some additional Use cases *(Login, Help)* play a secondary role, while the others *(Exploration* and *Communication)* symbolise the learning environment's functions that correspond to the geometrical image formation model (Fig. 1). The Use case *Exploration* is important for gaining personal manual or virtual experiences in the study of geometric figures, whereas *Communication* gives a sense to the image expression variety thus creating additional experience accents.

The abstract labelling of *Visitor* proposed selection of activities enables us to reveal the functionality of the learning environment in a simple way (without internal details).

In the real learning environment, the Use case *Login* represents that a pupil belongs to a concrete learning group. The Use case *Help* shows that each pupil has a possibility of learning with a teacher's help, and each teacher can get additional information about geometry and didactical support. The Use case *Exploration* covers all exploration activities shown in Fig. 3. The Use case *Communication* covers all communication activities shown in Fig 3.

In the virtual learning environment, the Use case *Login* is needed for pupil identification and gathering the pupil's data relevant to the teacher. The Use case *Help* presents technological information about the peculiarities of environment as well as holistic geometric education didactic for a teacher. The Use case *Exploration* covers exploration activities shown by a dashed line in Fig. 3. The Use case *Communication* covers all the communication activities listed and distinguished by a dashed line in Fig. 3.

In summary, the Use case diagram, used by UML for the situated geometry learning environment, concisely depicts a conceptual form of the created system. Situated cognition possibilities of the Use case diagram are illustrated in the Use cases of *Figure*, *Exploration* and *Communication*. All the Use cases are meaningful in both the real and virtual learning context. This demonstrates the suitability of the chosen UML language for describing the problems considered.

***UML Class Model for Situated Geometry Learning Environment***

A Class diagram of the situated geometry learning environment is needed for depicting the static environment structure. Such a structure is the result of further development of the conceptual model.

The most important issue in the software design, at least with an O-O approach, is to identify the right classes – data abstractions. The second most important issue is to identify the relations between these classes (Meyer, 2009).

Disassociating from class specifications, the Class diagram (Fig. 5) of the situated geometry learning environment illustrates the logical structure, constructed on the basis of the Use case diagram (Fig. 4). Such a structure is described by the learning method (*Exploration*, *Communication*) and its support environment. In the real environment, application of the learning method appeals to the leading teacher's role. In the virtual learning environment the learning environment itself can often direct towards the correct way. In the case of the mixed reality and situated learning, the help of both a teacher and a learning environment is equally important.

It is worth noting that communication in the situated geometry learning environment includes various activities (Fig. 3). Since learning has to happen in an authentic environment, there arises a technological necessity to separate some of the communication supporting services. Interface *ICommunicate* in Fig. 5 shows the communication when exploring geometric shapes, direct consultation with the teacher (questions raised by a student must be noticed and answered as soon as possible) and Wiki (intended for collective geometrical stories and vocabulary creation).

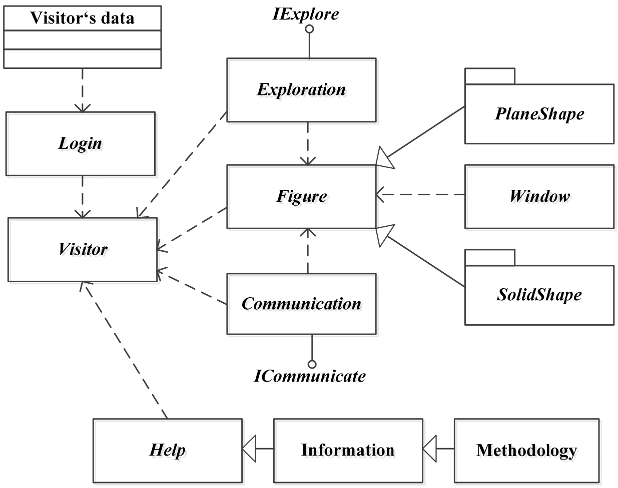


FIG. 5. CLASS DIAGRAM FOR THE SITUATED GEOMETRY LEARNING ENVIRONMENT

*IExplore* interface, shown in Fig. 5, can be characterised by polymorphism. Geometric shapes can be explored by real or virtual examination, drawing, constructing. Geometric construction in the real learning environment can be treated as a manual model development. Developing activities in the virtual learning environment can include shape tiling, drawing of particular details, description of the algorithm appropriate how to create a geometrical shape, uploading a picture of a geometric shape made by a pupil.

In summary, construction of the UML Class diagram for the situated geometry learning environment encourages us to seek additional insights, which helps purify the essence of such a learning environment. Polymorphism of an interface is based on the similarity of elements of the environment, while communication and exploration decomposition appear on the basis of situated cognition.

### *UML Activity Diagram for the Situated Geometry Learning Environment*

Algorithmic and logical implementation attributes can reveal dynamical functioning aspects of complex systems. The learning process in the situated learning environment is very complicated. Therefore the functioning model can be a tool allowing a deeper comprehension of such processes.

The Activity diagram for the situated geometry learning environment illustrates the logic and consistency of transitioning from one learning activity to another (Fig. 6). Here once again we appeal to the conceptual learning environment model as well as to the Class diagram for the situated geometry learning environment.

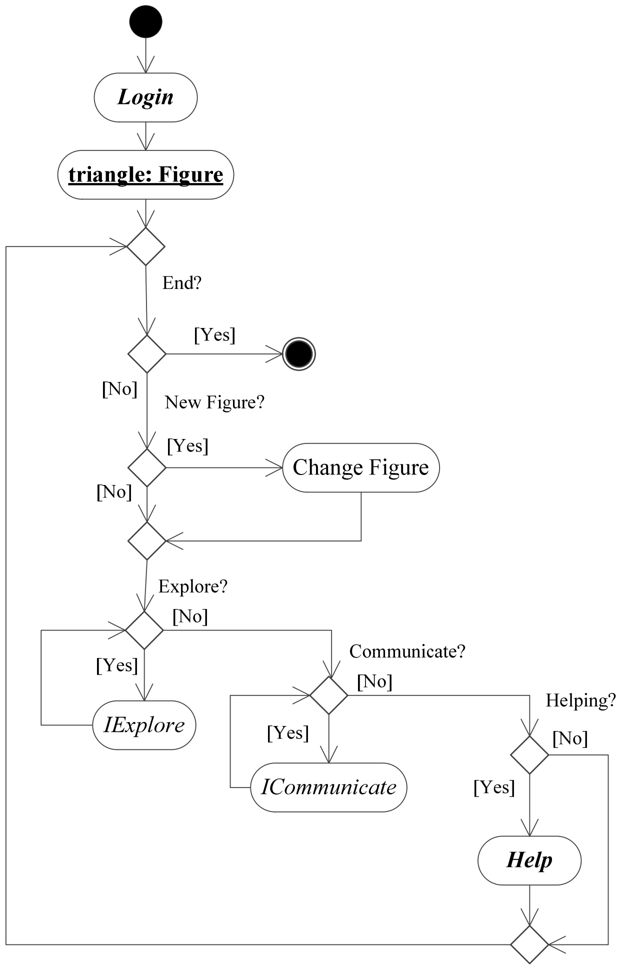


FIG. 6. ACTIVITY DIAGRAM FOR THE SITUATED GEOMETRY LEARNING ENVIRONMENT

The modelled Activity diagram is composed of the main dual structures, i.e. cyclically repeating activities *IExplore/ICommunicate* and solitary Help, Change Figure choices. The situated learning environment in this diagram is coded by the possibility to choose a relevant activity at a particular moment of time. Even though a set of options is rather wide due to the polymorphism, the form of the most general Activity diagram (Fig. 6) still has distinguished conciseness.

In the Activity diagram (Fig. 6) the object *triangle: Figure* means an activity with the first shape from the given list of geometric shapes. In the real learning environment, this selection corresponds to the main topic of a lesson. In the virtual learning reality, automatic selection of the initial object is needed in order to form a visual webpage window.

In summary, the activity model of the situated learning environment reflects adjustment abilities of wide learning activities.

In the mixed reality context, the Activity diagram can be interpreted as follows: potentially any particular learning activity can be real or virtual as much as it is needed for the pupil to understand the essence of the investigated object or phenomenon.

## Object-Oriented Approach and the Learning Design

Abstraction is a reduction of the information content of a concept, typically to retain the information relevant only to this concept (Larman, 2000). Abstract visualisation of the complex learning environment model highlights details of the intuitive imaginary education process. Application of the O-O approach in the education process can be considered not as a sequence of the known activities in advance learning, but as a situated cognition that depends on the educational situation.

From the O-O point of view, the Class abstraction is a tool to express the variety of a modelled environment. In the situated learning environment, where the authenticity of the acquired knowledge context is important, such a variety is best represented by the learning method. Abstract nature of the learning activities interface which revises the learning method, allows us to disassociate from non-relevant realisation details, in particular, the modelling stage, hereby increasing the visuality of the model.

The constantly growing and potentially applicable set of learning methods and dimensions of the real-virtual learning environment justify the application of O-O principles in modelling a learning environment.

The principle of inheritance is valuable in trying to understand the links between modelled abstractions as well as seeking to concisely represent related ideas.

The principle of encapsulation is useful, in particular at the learning environment modelling stage, by highlighting connections relevant only to the interaction of objects. In such a way, the learning design process becomes simpler, moreover, the modelling result itself becomes easier to comprehend.

TABLE 1 ADVANTAGES OF THE O-O APPLICATION WHILE MODELLING A COMPLEX LEARNING ENVIRONMENT

| **O-O central concepts and principles** | **Application in modelling of a complex learning environment** |
|---|---|
| Abstraction | Exclusion of the essence, reducing the level of detail, visualisation |
| Inheritance | Modelling of the abstract interface, compact visualisation of related ideas |
| Encapsulation | Exclusion of the connections relevant to object interface, simplification of modelling process, compact form of the model |
| Polymorphism | Easy addition or change of the learning content, compact form of the model |

The principle of polymorphism is relevant in adding/changing learning contents. A learning method can acquire different external forms when the priorities of the education content are changed. However, the most general learning environment model can remain unchanged in such a case.

In summary, the O-O central concepts and principles are highly important for creating a contemporary learning environment (Table 1).

A deep insight into the scope of modelled environment concepts enables us to create a learning environment model which can be abstract, concise, visual, and easily adjusted.

## Conclusions

We examined the main properties of the holistic geometric primary education modelling by using UML. On the one hand, discovered properties are determined by a particular purpose and complexity of the modelled environment. On the other hand, any integrated learning environment is complicated in its own way. Thus, the discovered properties reveal specific issues of the learning environment modelling, using the O-O approach.

The analysis of the geometric images formation model shows the complexity of holistic education in the mixed reality. Education has to be examined in the reality-virtuality coordinate system. Even the education environment can only be real or only virtual in a short time, educational situations more often involve a combination of these activities of a different nature. Consequently, the education environment modelling problem becomes insolvable if real and virtual learning environments are modelled separately.

UML has revealed some of the properties which can be important for the complex learning environment modelling:

- A situated learning process in the most general form is characterised by the following inheritance: activity interface → activity → learning method. The accent of all UML diagrams is the situated cognition.
- The situated cognition possibilities in the Use case diagram are symbolised by the use cases which elaborate learning methods. According to the O-O viewpoint, all the use cases are meaningful in both the real and virtual learning context.
- Additional insights help purify the essence of the modelled learning environment. If similarities of the environment elements are discovered, then the O-O principles can be applied. However, trying to realise the conditions of situated cognition, we are obliged to separate the communication and exploration services.
- The structure of the situated learning Activity diagrams renders wide opportunities for the adjustment of activities. The abstract nature of the learning activities assists in distancing from the information irrelevant to the comprehension of overall educational process functioning.

Therefore, application of the O-O approach to the learning design is justified when a complex learning environment is modelled. Application of abstraction, inheritance, encapsulation, and polymorphism principles grants the learning environment model conciseness and thus the education topic becomes easier to comprehend.

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