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# An approach to virtual laboratory design and testing

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**Abstract:** Laboratory experiments and research are important parts in natural science education. They supplement the theoretical learning material and contribute to deeper learn of a subject. The realization of such activities requires an appropriate laboratory equipment and reagents that are often either inaccessible or incomplete. Virtual labs solve this problem and provide the performing of the same experiment repeatedly without any restriction. An interactive laboratory environment engages pupils in active learning to enhance their understanding of processes and practical skills and promotes a successful e-learning strategy. Virtual Lab includes a lot of embedded experiments that the student must perform via certain scenarios. In the paper an approach to design of laboratory experiments for virtual lab environment and their scenarios implementation testing is suggested. Experiments design patterns are based on finite-state automaton model. The object-oriented approach for virtual experiment implementation is provided. For testing pattern a methodology of class testing is used. The suggested approaches are realized in the presented virtual laboratory environments for Chemistry and Biology that have been developed to support laboratory study in Armenian schools, colleges, and universities. These methods will be used in long-term research activity in the field of creation of virtual laboratories on different disciplines: organic and inorganic chemistry, physics, and biology as well as during developing others virtual laboratories.

**Keywords:** Virtual Experiment, Virtual Laboratory, Experiment Modeling, Implementation and Testing, Class Algebraic Definition, Class Testing, Test Case

## 1. Introduction

In the modern society e-learning is an inherent part of education and gives the students and pupils a proper possibility to get knowledge independently of time and place.

Laboratory experiments and research in different natural subjects essentially supplement the theoretical learning course and provide deeper acquirement of the learning discipline [1, 2]. The realization of laboratory experiments and research needs an appropriate laboratory equipment and reagents that are often either inaccessible or incomplete. On the other hand, even the laboratory equipment is complete, it is necessary and desirable to make the same experiment repeatedly with different substances with their various proportions and by different sequence of actions. Undoubtedly during the laboratory experiments' realization it is necessary to keep the precautionary measures whereas in virtual conditions the student is being given some free hand. The pedagogical agent can prevent the attempts of the dangerous actions making outline of warnings and undesired reactions and effects [3, 4]. At the same time it is desired to organize the laboratory study whenever and wherever without any equipments and reagents. So it is very important and actual to develop virtual environment for laboratory research.

The problems considered in the paper are related to definition of general templates for the virtual environment for laboratory studies in different subjects, creation patterns in order to design and test virtual laboratories supporting software, realization virtual laboratories according to these patterns. The problems include the identification of basic concepts, elements, operations for different laboratory experiments, relations between them as well as the main concepts of execution of virtual experiments.

The essential part of a virtual laboratory is a set of embedded experiments that the student must perform via certain scenario.

To develop virtual experiments and to provide the performance of experiments scenarios some design and testing patterns are described in the paper. Virtual environments for Chemistry and Biology laboratory research that have been developed to support laboratory study in Armenian schools, colleges, and universities, are presented.

It is intended that the suggested approach will be embedded in long-term research activity in the field of creation of virtual laboratories on different disciplines: organic and inorganic chemistry, physics, and biology as well as during developing others virtual laboratories. It can be used by subject-specialist for adding the new experiments in developed virtual laboratories. The software developer can use the created patterns for developing and testing of others virtual laboratories.

## 2. Virtual Laboratory Experiment Modeling, Implementation and Testing

As a pattern for design of a virtual laboratory experiment a finite-state automaton model is suggested [5]. The experiment is presented as an automaton, and the automaton's states correspondent to those states in which the experiment can appear during the experiment implementation. The automaton's states are classified as following:

initial state – the state from which the experiment begins,

state without any effect - the state in which any effect doesn't occur,

state with an intermediate effect- the state in which some effect can occur but it is not a final effect of the experiment,

state with the final effect - the state corresponded to the experiment's final result.

Automaton's transitions correspond to activities performed by concrete substances and tools that can lead to changing of the experiment common state. An experiment performance scenario is presented as a path from the initial state to any other state. On these paths a state may be repeated only if some transition in the automaton is done under an edge which doesn't change a state of the automaton. If there was a change of the automaton state then returning to any of previous states isn't possible.

For the implementation of the automaton modeled experiments the object-oriented approach is suggested. For this aim appropriate data types are needed.

Let us specify some of them for chemical research. Data type Substances={S1, S2,,…} describes the chemical reagents used in an experiment, for example, acids, alcohols, data type Tools={T1, T2,,…} defines all the tools used for experiment performance, for example, glass, tube, spirit lamp, data type SubstanceEffect describes chemical reagents' set received by some effect achieved etc.

Each experiment is presented by a separate class. Class data-members' values represent a current state of the experiment, and class methods represent activities carried out with tools and substances during the experiment. A method can change the experiment state.

So a class for an chemical experiment should be declared via the following pattern.

```
enum Substances={S1, S2,…};
enum Tools={T1, T2,…};
enum SensitizableEffects={T1, T2,…};
typedef set<Substance> SubstanceEffect;
typedef pair< SensitizableEffects, SubstanceEffect> Effect;
class ExperimentName
{
private:
set<Substance> sSubstance, sSubstanceEx dended;
set< Tools > sTools, sTubes;
map< Tools, set<Substance> > ExpState;
map< Tools, Effect > ExpEffect;
public:
Method1(…);
Method2(…);
Method3(…);
…};
```

The variable sSubstance holds the set of the substances explored in this experiment while the variable sSubstanceExdended holds the set of auxiliary substances used in this experiment. The variables sTools and sTubes are reserved for tools and tubes. The variable ExpState represents a current state of the experiment, i.e. it is a pair where a mapping of toolset into set of substances is presented. The variable ExpEffect holds a chemical effect occurred in some state of experiment.All the listed variables are initialized by class constructor.

The class for the experiment creating an ether (E) from two types of organic acids (AC1, AC2) and two types of alcohol (AL1, AL2) is outlined below.

```
enum Substances={AC1,AC2,AL1,AL2,E};
enum Tools={Measure,Glass, Tube, Bath, Tunnel, Stopper, Fire};
enum SensitizableEffects={no_effect, odour, colouration, dimming};
typedef set<Substance> SubstanceEffect;
typedef pair< SensitizableEffects, SubstancEffect> Effect;
class EtherFromAcidsAndAlcohols
{
private:
set<Substance> sSubstance, sSubstanceExdended;
set< Tools > sTools, sTubes;
map< Tools, set<Substance> > ExpState;
map< Tools, Effect > ExpEffect;
public:
EtherFromAcidsAndAlcohols (…);
void fillInMeasure(Substances);
void putMeasureInBath(Tools);
void fillMeasureInGlass(Tools);
void fillGlassInTunnel(Tools);
void showEffect();
};
```

For a virtual laboratory testing we use the TACCLE (Testing An Class and Claster LEvel) methodology where an algebraic definition of classes is provided [6]. Such a definition of class has two parts: syntactic declaration and semantic specification. Syntactic declaration is a set of class interfaces as given above, and semantic specification is a set of axioms that describe class methods behavior. The semantic specification of the class is based on the finite-state automaton model described the experiment and may be presented in XML format [7]. A part of the XML description of semantic specification is outlined below. For each method both initial and next states are indicated.

-<experiment name=" EtherFromAcidsAndAlcohols">
-<states>
-<state name="S0" state ="init">
-<transitions>
<transition name=" fillInMeasure(AC1)" priority="1" nextstate="S1"/>
<transition name=" fillInMeasure(AC2)" priority="2" nextstate ="S2"/>
<transition name=" fillGlassInTunnel()" priority="4" nextstate ="S3"/>
</transitions>
</state>
+<state name="S1" state ="no effect">
+<state name="S2" state ="mid effect">
+<state name="S3" state ="fin effect">
</states>
</experiment>

Test cases for experiment implementation testing are terms. A term is a sequence of a class methods' calls that represents the sequence of actions performed in the experiment.

Let _exp.Method(c1, c2,…,cn): ExpState*C1*C2*…*Cn → ExpState is an elementary term, where ExpState is a type for experiment's states, and C1,C2,…,Cn are types for method's parameters. An elementary term provides an experiment transition from a state to another.

We define the applicability operation on terms. Let u=f0f1…fi and v=g1g2…gj are terms. It is said that the term v is applicable to the term u if and only if the output state of the term fi is an input state for the term g1. In this case w=u.v is a new term.

For a class C we distinguish four type of methods: observers that return the values of the attributes of the experiment object, creators that initialize the experiment object, and constructors and transformers that transform the states of the experiment object. For example, the method showEffect() is a observer for the class EtherFromAcidsAndAlcohols while fillInMeasure(C1) and putMeasureInBath() are transformers. The current state of an experiment is the combination of current values of all attributes of the object presented the experiment.

An observable context on a class C is a sequence of constructors and transformers of C followed by an observer of C. For example, the term fillInMeasure(C1). putMeasureInBath().showEffect() is an observable context on the class EtherFromAcidsAndAlcohols.

An observable context sequence on a class C is a term $oc=oc_1.oc_2....oc_n$, where $oc_i$ (i=1,2,...,n) is an observable context, and $oc_j$(j=2,...,n) is applicable to $oc_j$-1.

A term applied to the experiment object transforms it to some state.

On the set of terms and objects it can be defined different types of equivalence. Terms that lead the experiment to the same state are called equivalent. Two objects O1 and O2 are said to be observationally equivalent if and only if the following condition is satisfied: if no observable context oc on class C, is applicable to O1 and O2, then O1 and O2 are identical objects. Otherwise, for any such oc on C O1. oc and O2. oc are observationally equivalent objects.

Note that if class implementation satisfies with class specification then for two equivalent terms u1 and u2 the objects O.u1 and O.u2 are equivalent, and for two nonequivalent terms u1 and u2 the objects O.u1 and O.u2 are nonequivalent.

For terms transforming we define the loops exclusion operation on terms. If $u=f_0f_1\ldots f_n$ is a term and there are i, j ($i<j$, $f_i=f_j$) and such observable contexts oc1 and oc2, that

O.oc1 and O.oc2 are equivalent,
$f_i$ is applicable to oc1,
$f_j$ is applicable to oc2,
O.oc1.$f_i$, and O.oc2.$f_j$ are the same,
then fi is deleted from the term u.

Any term on experiment class can be used as a test case for experiment implementation testing. For example, the term fillInMeasure(C1).putMeasureInBath() is a test case for the experiment E if it is applied to the object E.

For the complete testing the class must be tested on the pairs of both equivalent and nonequivalent terms. These terms are constructed via XML description of semantic specification of the class.

The infinite set of terms is reduced to an finite set of terms with loops exclusion operation. This set can be embedded into the test driver to test the laboratory automatically.

# 3. Case Study

Virtual environments VirtChemLab and VirtBioLab for Chemistry and Biology laboratory research based on described approach are developed by authors [8, 9]. About 50 traditional laboratory experiments of Inorganic and Organic Chemistry and Biology are modeled, realized and embedded into these systems.

The created environments allow to carry out the conventional chemical and biological experiments interactively with various collection of substances and objects which are typical for that experiment, to understand chemical reactions in experiment between substances. Working in the virtual laboratory helps the student to recognize the properties of suggested substances in frame of that experiment, as well as to organize practical laboratory research wherever and whenever, to study the experiment's correct scenario by attempts and mistakes method, to observe experiments results by different visual effects, chemical formulas and animated molecules (Fig. 1).

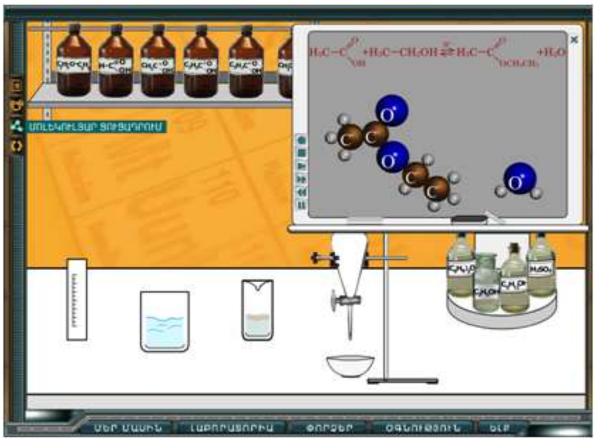

***Figure 1.*** *Chemical formula and animated molecules.*

The same experiment can be done many times with different substances with different proportions to receive deeper knowledge about investigated chemical and biological reagents. The colorful didactic materials, illustrations and different multimedia animations for chemical and biological experiments make learning more interesting and easy to understand. Laboratory study is accompanied with recommendations, advice and remarks. In virtual laboratories there are also the information making the theoretical base of the experiment and textual description of experiment's scenario with sound.

The virtual environments provide also experiments' demonstration in real chemical and biological laboratories taken by a video camera as well as a gallery that obtains necessary laboratory equipments, glassware, tools and reagents and so on. In the gallery there is a brief information about each substance and its chemical and biological properties.

The lab equipment and reagents availabled to learners are placed in virtual laboratory depending on the experiment to be made. All actions in virtual laboratory are made by mouse. The correct selection of experiment's substances and tools leads to simulation of real effects and actions by activating the corresponding animations (e.g. pouring the solution into the glassware, mixture color changing etc.). There is a blackboard on which the comments and recommendations of pedagogical agent and experiment's reactions formulas are placed.

## 4. Conclusion

To develop the suggested approach for virtual laboratories design and testing the main following problems are explored:

- identifying of a uniform approach on the problem of interactive experiments designing.
- establishing and identifying main concepts of execution of virtual laboratory studies.
- identifying of experiment's basic elements, operations and relations between them.
- identifying of basic methods to do experiments interactively.
- identifying of means and ways for experiment's reagents' characteristics presentation.
- developing of the formal model for laboratory experiment's scenario and it's adaptation to appropriate mathematical computing model.
- developing of virtual laboratories design patterns.
- identifying of object oriented approach on laboratory experiments' scenarios programming.
- identifying of the role of virtual teacher during laboratory research.
- simulating of 2-3 classic experiments on different subjects.
- defining of virtual laboratories testing methodology and testing patterns used the testing theory of object oriented software on class level.
- elaborating of methods for constructing the test cases complete system.
- the suggested approaches implementing for some real-life examples.

## 5. Further Work

We continue works in direction of developing Virtual Laboratories to cover the other natural subjects, expand their functional abilities, provide much more experiments and increase the flexibility of these systems. The modifications of the systems are planned to implement in following directions:

- increasing the interactivity in virtual environments;
- design and testing template toolset extension;
- user interface improvement;
- creation of new services to support connection between laboratories and practicing classes;
- feedback system developing;
- translation into English and Russian.

According to W3C consortium standards regarding Web Ontology and Learning Objects we assume to continue our works by using OWL to describe basic elements of laboratory research as well as semantic relationship and dependency between different components and parts of a laboratory experiment. We suppose to create mechanisms and tools to analyze the quality of such laboratories to provide the quality of e-education.

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