

# Technology Enhanced Learning with Subject Field Multiplicity Support

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## ABSTRACT

In this paper, we discuss some ideas and tools for Technology Enhanced Learning (TEL) capable of spanning over and integrating a multiplicity of subject fields. Multidisciplinary, interdisciplinary, and pandisciplinary educational content, its presentation in different forms, as well as methods and technologies for its integration in TEL are considered. Tangible interfaces based on digitally enhanced physical objects, including printed documents, that facilitate a new level of content-aware interactivity are introduced and a Tangible TEL (T-TEL) is proposed. With this we attempt to establish a cooperative TEL framework for integrating independently obtained results involving several research projects both at national and international levels and spanning over two continents.

## Categories and Subject Descriptors

K.3.2 [Computers and Education]: Computer and Information Science Education – *computer science education*; I.6.8 [Simulation and Modeling]: Types of Simulation – *animation, visual*; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism – *animation, virtual reality*; D.2.2 [Software Engineering]: Design Tools and Techniques – *software libraries*; J.m [Computer Applications].

## General Terms

Design, Theory

## Keywords

Technology Enhanced Learning, Virtual models, Science and Art education, Tangible interfaces

## 1. INTRODUCTION

Technology Enhanced Learning is a relatively new concept for which there is no universal, truly acceptable definition so far. The role of technology in education has been a main research and exploration topic of several European projects, like Kaleidoscope,

PROLEARN, STELLAR, Share.TEC, TARGET, and others.

Effective co-learning of a multiplicity of disciplines is a challenging but achievable task if appropriate technologies are brought to education. Indeed, it is a common practice for educational institutions to offer multidisciplinary courses, which mix otherwise distinct disciplines. In some cases multidisciplinary efforts evolve into interdisciplinary by sharing approaches and techniques across various disciplines [17]. The design of teaching materials suitable for interdisciplinary studies is not, however, as straightforward as is the one for multidisciplinary subjects.

Subsequent sections of the paper are structured as follows. Section 2 begins with discussing the support of multiplicities of subject fields in the context of inter-, multi-, and pan-disciplinarity. Section 3 follows with an introduction to TEL interaction interfaces. Sections 4 and 5 treat Virtual Reality in TEL and the Tangible TEL respectively. The final Section 6 summarizes the progress of current research and presents plans for continuing work.

## 2. PANDISCIPLINARITY AND SUBJECT FIELD MULTIPLICITIES

Most of the new technologies and their corresponding professions and educational subjects emerge at the intersection of relatively close domains. For example, *Mathematics* and *Computer Science* share a lot of concepts and provide a productive foundation for crossing disciplines. Pandisciplinarity, on the other hand, covers many disciplines, which are not necessarily close [15]. The design and development of pandisciplinary educational content and learning units that are not bound to a specific subject is a challenging task. If successfully created, though, such units will span over a multiplicity of fields and one and the same unit could be reused within the contexts of different disciplines.

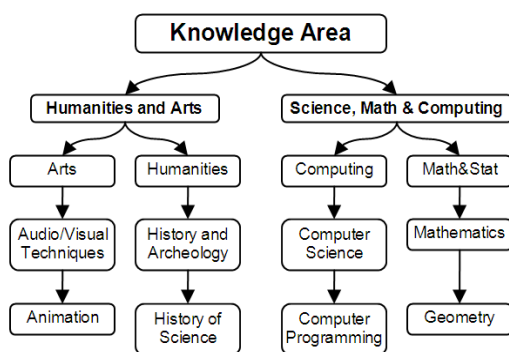
One of the approaches to measure how close two disciplines are, is based on the taxonomical distance between them. If we use the *Knowledge Area* branch of the Teacher Education Ontology [1] (see Figure 1) defined by the Share.TEC project we will find that *Mathematics* is close to *Computer Science* as they have a common predecessor.

However, it is possible to arrange disciplines in different ways using other academic, scientific or historical criteria. The Share.TEC's *Teacher Education Ontology* (TEO) classifies topics in 9 categories, while other systems use more categories and shallower taxonomies. The *Joint Academic Coding System* (JACS)

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**Figure 1. A small fragment of Share.TEC's TEO**

in UK uses slightly less than 20 top-level categories, the *Australian and New Zealand Standard Research Classification (ANZSRC)* lists 22 top-level categories, while the *Classification of Instructional Programs* of the National Center for Education Statistics (USA) has 53 top-level categories.

Different taxonomies produce different and sometimes incompatible results in respect to finding how diverse is a set of disciplines. Emerging research fields often create numerous cross-links within the taxonomies that cannot fit in their tree-like structure and may lead to confusion in classification. *Mechanics*, for example, is classified under *Engineering* in JACS, under *Physical Sciences* in ANZSRC, and under *Science, Mathematics and Computing* in TEO. It may happen that a set of disciplines is spread over different categories in one taxonomy, but is contained in a single category in another taxonomy.

A pandisciplinary approach covers a larger set of disciplines, which are unlikely to exist in a single category in any (or most) of the known taxonomies. The materials, described in this paper, cover numerous disciplines: *Geometry, Computer Graphics, Computer Science, Mechanics, Engineering, Art, Film production, History of Science, Linguistics*.

A limitation, but not disadvantage, of many teaching and learning materials is that they are precisely focused on predefined disciplines. Our subject field multiplicity approach overcomes this limitation by allowing the same teaching content to be used in mono-, multi-, inter- or pan-disciplinary materials depending on the educational goals. Using the same materials a teacher can make one discipline dominant in some classes and another discipline dominant in other classes. This greater degree of freedom, however, comes at a price – the development of such materials is harder and few teachers are willing to adopt this non-traditional approach [8].

### 3. TEL INTERACTION INTERFACES

Technology Enhanced Learning is applicable to various educational environments that may or may not involve computers. Since the learning process in such environments has to be technology bound, technology awareness of the learners becomes an important issue.

Using sophisticated equipment and/or software in education may actually incur to learners too high, sometimes unacceptable, burden that has little to do with the specific educational targets. For example, despite all advances in computer technologies and

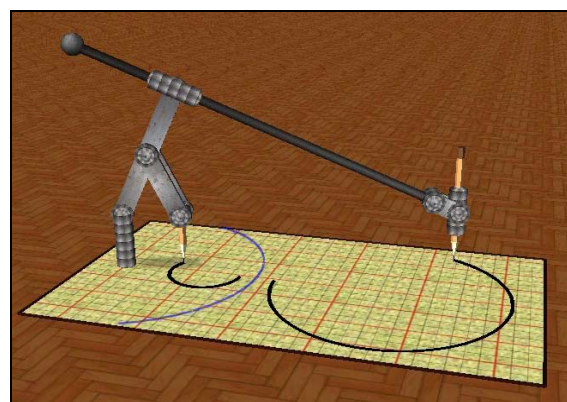
improvements in their usability, many people still struggle with computers and need special training to develop skills and build confidence.

Virtual Reality approaches may partially alleviate this kind of problems by prompting users to employ well learned interaction patterns from the physical world in the virtual world. But in e-learning users mostly deal with traditional computer input and output through keyboards, mice, and monitors. Touch screens supporting pen and finger based input and simple gesture interactions are just beginning to take over. Specialized interaction devices such as tablets and digitizers, haptic and 3D input, and other advanced techniques have still to earn their place in e-learning. But e-learning is not confined solely to computers so artifacts from the real world often need to be incorporated into it.

In the more general context of TEL the question of how to handle direct interactions with physical object from the surrounding environment can become of a primarily research interest. Finding a good balance between the virtual and the real in TEL has always been a difficult task. Virtual laboratories [16] and experimentation in simulated environments built around numerical models of various physical phenomena [13,14] are making their way in TEL and e-learning but there are tasks for which hands on experience will always be required. Taking the long way from the classroom to the pilot seat, for example, trainees first study the theory and learn about flight controls with dummies and various cabin interiors. Then for prolonged periods training on flight simulators with tangible controls, convincing video feedback and realistic physical motion is conducted. Only afterwards it comes to real planes and flight instruction.

### 4. VIRTUAL REALITY AND TEL

Within the scope of our on-going *Virtual Reality in the Classroom* research project, we present and discuss in this section an instructional set of materials, aimed to support technology enhanced learning and pandisciplinary in education. Currently a collection of i) *virtual mechanisms* for curves, surfaces, and geometrical transformations as well as ii) *ellipse-related movies* with computer-generated 3D animations and iii) *user friendly libraries* for teachers and students are included in the set. Conceptual graphs of explicit and implicit relations between geometrical notions and a book of mathematical problems stemming from the materials in the set will be added to it in the future.



**Figure 2. Inversograph.**

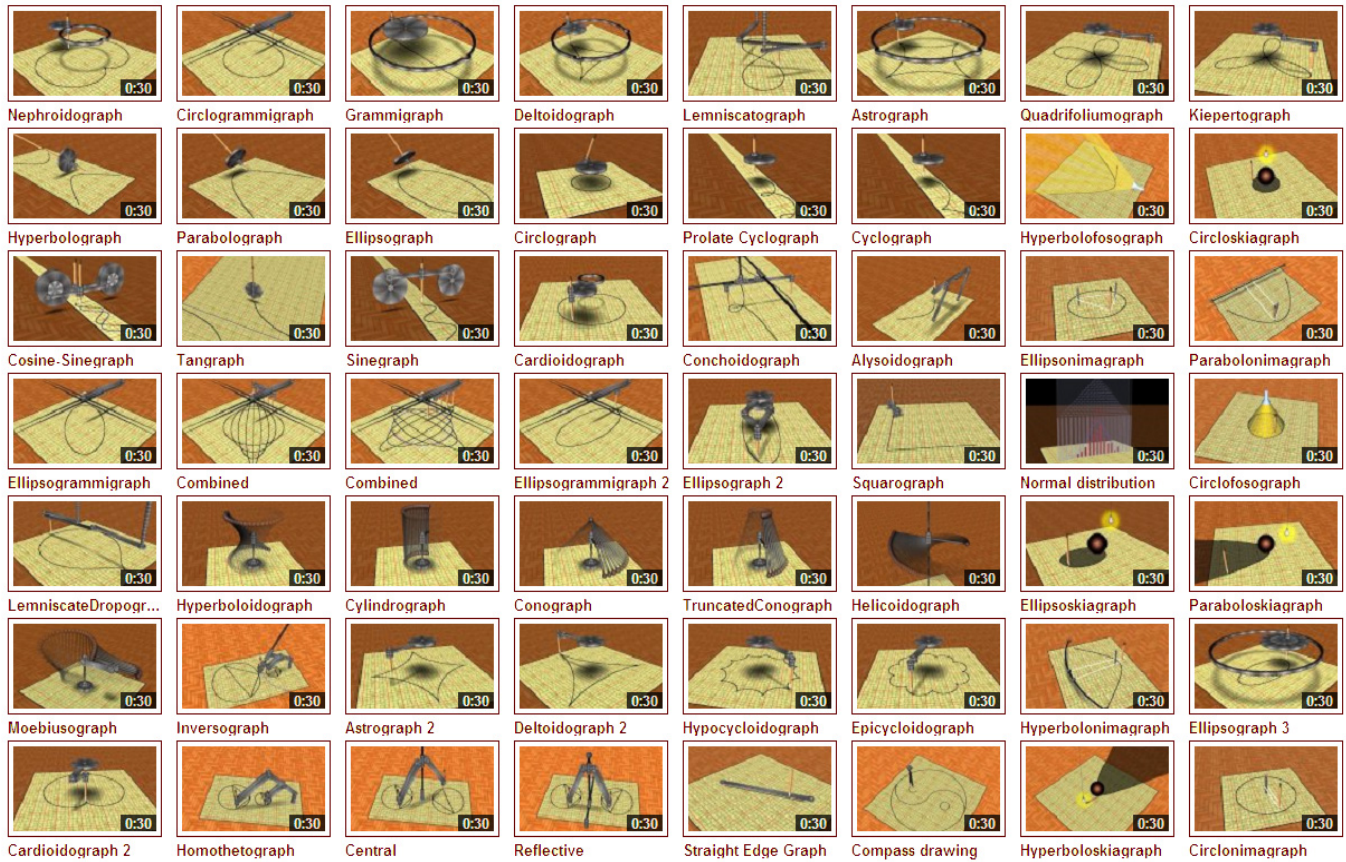


Figure 3. The Collection of 3D virtual devices

Developed educational content, its structure, and its composition have been specifically designed and optimized in order to achieve higher *educational density*. In the context of our work *educational density* constitutes a measure of the educational potential of developed educational sets.

A typical TEL-related material has educational value at functional level – i.e. the value reached while just using the material. Our set of materials goes beyond this point, by allowing students to study and explore the fabrics of the materials. Thus, its educational potential is not only at functional, but also at structural level.

For example, the program for animating the Inversograph (i.e. a device performing the geometrical transformation *inversion*– see Figure 2) can be used as a traditional TEL material in a *Geometry* lesson while its source code can be used in a *Computer Science* lesson covering the topic of *Object-oriented Programming*. It can be also used in *Physics* or *Computer Graphics* classes as a foundation for build variations and new models.

All software that we develop and introduce here supports this educational duality – applications can be used just as applications, but they can also become templates. This relates to our broader goal of making students not mere consumers, but also producers.

The collection of *virtual mechanisms* included in the set comprises of more than 60 virtual mathematical devices (see Figure 3) providing easy to rationalize geometrical constructions. Some of the virtual models represent different perspectives of one and the same mathematical concept revealing both its variant and

invariant properties [7]. For example, there are devices that illustrate the construction of a conical section based on several distinct but yet equivalent curve definitions.

Models in the collection could be used as *glass-boxes*, viz. they are available in two complementary formats – as executable programs and as standalone animations. Animations are meant to raise curiosity and to provide food for reflection, whereas programs could be considered as implementations of model-like hypotheses about various mathematical constructions.

The glass-box concept allows students to see the inside of every model and to learn how its components are defined and managed. Students are then encouraged to modify existing models and construct and experiment with new ones [5].

Animation design theory and practice go well beyond the scope of this paper. However, except for the video collection, our set of teaching materials features a short *ellipse construction movie* (see Figure 4) that demonstrates some animation techniques applicable to film production. The source code of the film is made available for students so that they can learn about camera movements, sound synchronization, timeline management, etc. This is an illustration of how a purely artistic motion picture artifact can be loaded with various types of educational content and employed in pandisciplinary teaching. For further involvement of such animation in teaching we are currently preparing a related set of mathematical problems that stem from the animation and hints for solving them can be obtained through the animation.



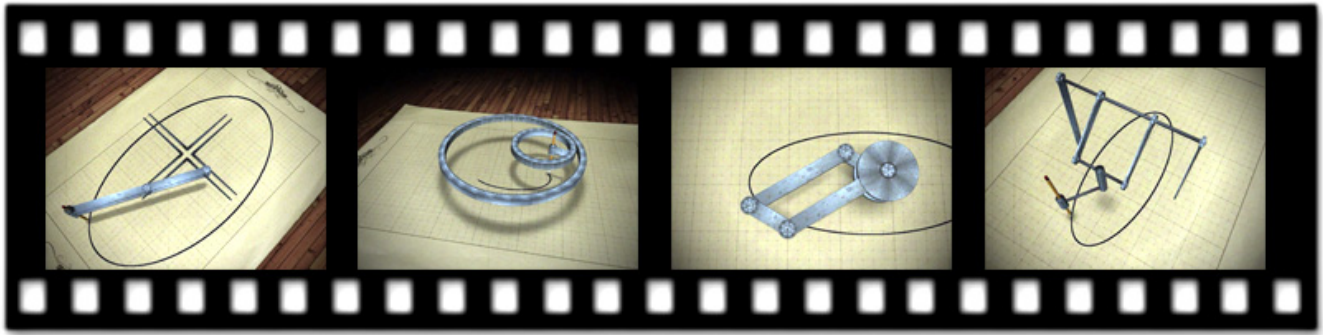


Figure 4. Frames from the computer film "Ellipses..."

The final component of our educational materials set consists of a user-friendly software library with core elements of implemented devices. For illustration we show in Figure 5 stereo views of a 3D Hyperbolograph device constructed with the library. The library seamlessly integrates in Elica (Educational Logo Interface for Creative Activities) and provides extended functionalities, normally not present in the initial collection, such as:

- direct creation of new virtual devices and exploration of their properties and behavior,
- interactive observation of such devices with possibilities to generate animations sequences (including stereoscopic ones), and others.

Elica is a research-oriented programming environment, featuring embedded support for pandisciplinary educational content design and development and for building of educational software [6]. It is used in the Faculty of Mathematics and Informatics at Sofia University for teaching *Languages and Environments for Education and Computer Graphics* [3] as well as in several European projects related to TEL [4].

## 5. THE TANGIBLE TEL

It is not surprising that hands on experience or learning by doing is recognized as one of the best learning practices. But given the resource limitations and time constraints that researchers face, some combined approaches are starting to get more attention. Just as in the case of employing flight simulators for training of pilots, one can envisage hands on experience activities in TEL that are

based on real physical objects. Such objects, though, do not need to be fully functional and experienced in their natural context. With adequate technological enhancements of the learning environment one can use such physical objects as interface components ensuring smooth and natural interactions.

One fundamental issue related to direct interactions with physical objects is their identification and tracking. Showing a physical object to a person is different from showing it to a robot or to a computer with a camera input. The person can make highly intelligent analysis of the scene, derive the context, and extract and recognize the object. Computers and robots, on the other hand, are much more limited in this regard and often reliable object identification and tracking are impossible to achieve. If proper identification and tracking was done, however, computers can provide in principle far better service and feedback.

One of the approaches that we undertake to address the above described problem is based on digital encoding of surfaces of physical objects. Different methods can be used to physically implement such an encoding; from regular printing and labeling, to direct printing on various surfaces, to shaping and direct printing of 3D structures, and to embossing and laser engraving of surface and undersurface layers of various physical objects.

The choice of the code to be employed is also an important issue that happens not to be trivial. Indeed most of the widely seen codes fall into the bar-code category where digitally encoded marks with distinct predetermined shape and size are employed. But for global encoding of objects, other codes, namely surface filling or carpet codes, appear to be much more suitable. In our



Figure 5. Stereoscopic images of Hyperbolograph. Left two snapshots are for cross-eye viewing, the one on the right is for viewing with red-cyan anaglyph glasses.

implementations and experimental work we use CLUSPI surface filling codes based on the Cluster Pattern Interface method co-invented by one of the authors [12]. CLUSPI codes are unobtrusive, practically invisible by naked human eye, and can be easily parameterized to meet various application requirements.

CLUSPI applications have been explored in many different areas, like tangible and physical interfaces for interactive multimedia presentations [9]; dynamic digital content accessible through common optical recognition; and interactive printouts integrating multilingual multimedia and sign language resources [10].

Moreover, CLUSPI applications may have significant impact on TEL and e-learning. Printed educational materials can be enriched by layers of additional digital data [2] thus converting the materials into digitally enhanced tangible interface components [11].

## 5.1 Human-Computer Interactions and Interfaces

Research carried out at Vision Information Processing Laboratory at Research Institute of Electronics focuses on imaging and extraction of semantic surface information for localization, object identification, and interaction support. In the scope of extreme imaging science studies on advanced surface communication carriers are conducted and methods and technologies for surface and undersurface laser marking and volumetric engraving are investigated.

The research on surface communication carriers has a long history with more than 50 scientific publications, multiple applications for patents worldwide, and several granted patents in Japan and USA. The research is focused on:

- Encoding of semantic surfaces cluster pattern interfaces with augmented capabilities.
- Fundamental research on surface filling codes.
- Parametric studies and optical track and spectrum expansion investigations of surface code reader devices.
- Advanced methods for printing on flat and curved surfaces, including 3D printing, shaping and encoding of complex physical objects, as well as technologies for embossing and surface and undersurface laser engraving and volumetric marking.

## 5.2 Relations to Other Projects

The work described in this paper is related to research and development carried in several other international and national projects. Although some of the projects are already finalized, there are still several, which are active and provide grounds for application and dissemination of the developed materials.

The project *InnoMathEd*<sup>1</sup> (*Innovations in Mathematics Education on European Level*) emphasizes on the inquiry based learning. It is funded by the European Commission and partners are educational institutions across Europe. The goal of the project is to give students the chance to deepen their mathematical understanding and to acquire key competences essential for

lifelong learning. Several educational materials in the project are developed with Elica.

The goal of the FP7 project *TARGET*<sup>2</sup> (*Transformative, Adaptive, Responsive and Engaging Environment*) is “to research, analyse, and develop a new genre of Technology Enhanced Learning environment that supports rapid competence development of individuals”. Partners in this project are educational, research and industrial institutions from Europe. The educational materials described in this paper may be converted into learning assets that “live” in the *TARGET*’s knowledge ecosystem.

The other FP7 project *Share.TEC*<sup>3</sup> (*Sharing Digital Resources in the Teaching Education Community*) is focused on supporting the teacher education community by sharing educational resources. The project collects information about relevant resources and classifies it according to dedicated ontology. Elica and some of the teaching materials described in this paper are used in courses for students that will become teachers in Mathematics and Informatics. Resources, developed in relation to these courses will be “harvested” by the *Share.TEC* server and their metadata will be included in the global European-wide digital repository.

## 6. FUTURE PLANS

The works presented in this paper present the current state of an on-going research in two areas of the Technology Enhanced Learning, namely, using interdisciplinary and multidisciplinary educational materials, and using tangible physical interfaces that provide additional digital layer of information.

Some of the teaching and learning materials, like the computer-generated film and the collection of virtual mechanisms are already developed. Others, like the user library and the Book of problems are still in the process of initial design. It would be a real challenge to design these teaching materials separating educational issues from technological ones. Thus learners would be screened from unwanted technology intrusions. We propose to put the focus of our future collaboration on the interface layers that connect users to TEL environments. By adding a direct interaction model we extend TEL environments by providing tangible interfaces and direct interaction capabilities.

A milestone in the future development is to support not only learners, but also educators. Teacher’s guides, exemplary lesson plans and lessons are fruitful ground for effective use of tangible interfaces. These materials can be evaluated by test groups of students and in-service teachers from both institutions. All the materials will be shaped as properly tagged learning objects that could be directly accessible by international digital repositories like the one provided by *Share.TEC* or that could be promoted to learning stories in the knowledge ecosystem of *TARGET*.

All above is basically about bringing in tangible interfaces with direct interaction functionalities and creating novel Tangible Interface TEL environments supporting a new approach in learning – the Tangible Technology Enhanced Learning.

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<sup>1</sup> <http://www.math.uni-augsburg.de/de/prof/dida/innomath/>

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<sup>2</sup> <http://www.reachyourtarget.org/>

<sup>3</sup> <http://www.share-tec.eu/>

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