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# INTEGRATING MATHEMATICS AND SCIENCE WITH ICT: A PROBLEM-CENTERING STRATEGY IN A GREEK SECONDARY SCHOOL

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**ABSTRACT**: This paper discusses a problem-centering strategy in integrating mathematics and science with ICT in a secondary school, in Greece. Integration involves establishing ties between scientific and mathematical sub-fields. The problem-centering strategy involves enlisting the knowledge in two or more disciplines to address particular tangible and real-world problems. In this pilot study, the problem-centering strategy was applied to two classrooms of a secondary school in Athens. Its advantage was that it brought together the disciplines of mathematics and science with ICT use (as a tool). Pupils, aged 13-14 years old, carried out learning activities integrating mathematics and physics in a computer environment using the "Geogebra" software. The learning activities focused on resolving tangible problems. This approach seemed to have improved pupils' motivation to learn mathematics.

**Key words:** Mathematics, science, ICT, problem-centering strategy, interdisciplinary approach

## INTRODUCTION

Several studies back the benefits of incorporating a multi-disciplinary curriculum. Research in the area of education, as well as in cognitive science, suggests that curriculum variations featuring an inter-disciplinary curriculum are likely to promote more learning (Loepp, 1999). Throughout the 1990's, curriculum integration and its application has been a consistent and important theme in education reform strategies, yet very few schools have adopted this reform in practice (Wisconsin Department of Public Instruction, 1999). This has happened despite praise from parents and pupils who describe the approach as valuable and challenging (Reid & Feldhaus, 2007); despite recommendations from many experts in the field and standards initiatives in science, mathematics, and technology that call for implementation of a multi-disciplinary approach; and despite research that shows integrating the math, science, and technology education curriculum helps pupils across a wide range of academic achievement (Wicklein & Schell, 1995; Bailey, 1997).

This paper discusses a problem-centering strategy in integrating mathematics and physics with ICT in a secondary school, in Greece. This is an introductory pilot study, since we still collect data from classroom practices. Three terms which are relevant to the study are defined here, for clarity. *Integrated Curriculum* - Two or more teachers from different disciplines working together to coordinate their course instruction, develop materials, link academic and occupational skills, and develop varied instructional strategies (Wisconsin Department of Public Instruction, 1999). *Interdisciplinary Curriculum* - A term that can mean any of the following: (i) Applying methods and language from more than one academic discipline to examine a theme, issue, question, problem, topic, or experience. Interdisciplinary curriculum creates connections between traditionally discrete disciplines such as mathematics, the sciences, social studies, or language. An interdisciplinary curriculum may be pursued by individual teachers working on a particular unit or among teachers planning together, (ii) The process teachers use to organize and transfer knowledge under a united


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theme (Maurer, 1994). Finally the term *ICT* (*Information and Communication Technology*) is used as synonymous to *computers* and *technology*.

## INTERDISCIPLINARY APPROACHES IN THE LITERATURE

Several studies support the benefits of incorporating a multi-disciplinary (or interdisciplinary) curriculum. Wicklein and Schell (1995) performed four separate case studies using a multidisciplinary approach to mathematics, science, and technology education. The goals of these case studies included increasing the interest level of the pupils in these subject areas, to help teachers to understand that their particular instructional areas did not stand alone within the curricular offerings, to improve pupils' attendance in school, and to transfer learning to unique problems. Through the application of "hands-on and minds-on" curriculum, the pupils understood the practical uses of the three instructional areas (Project Lead the Way, 2007-2008). For example, pupils were able to see direct applications of math and science to their everyday life through a variety of technology-based activities. Students demonstrated more motivation by reducing their absences from school and discipline problems based on the school records from the previous year. Furthermore, pupils demonstrated an appreciation for the structured learning activities, were able to perceive the importance of working together to solve a common problem, were able to appreciate the occupational strategies of modern businesses and industries, and demonstrated an improvement in self-esteem (Wicklein & Schell, 1995; Rossiter, 2002). The findings from this case study were not limited to pupil improvements. Faculty agreed that a multi-disciplinary approach created a learning atmosphere that provided pupil with a unique opportunity to learn in a much broader context. In addition, it allowed them to teach more effectively by revealing that pupils had been trained to dismiss subject matter learned in one classroom as having little or no relevancy to another. Research has also reported that motivation for learning increased when pupils worked on real-problem elements. When pupils were actively involved in planning their learning and in making choices, they were more motivated and exhibited fewer behavior problems. A multi-disciplinary curriculum was consistent with increased self-direction, improved attendance, higher levels of homework completion, and a more positive outlook towards school and academics. Inter-disciplinary education curriculum helped pupils make connections, solve problems and addressed better pupils’ learning styles.

It is a challenging -but not an easy- task to integrate mathematics and science into the rest of the secondary school curriculum. The challenge comes from the specialization of knowledge in these areas, the use of different sets of terminology, as well as a tradition of teaching these subjects in a way that emphasizes singular facts and precise tools over broad concepts and generalizable ideas. Even within the sciences and mathematics, the separation between the different sub-fields is so rigorously maintained and the boundaries so clearly drawn, that the internal integration within them is not a minor task. Integration involves establishing ties between scientific and mathematical sub-fields. Furthermore, all too often such sub-fields are represented as (indeed reduced to) collections of facts and formulas to be utilized to address decontextualized problems. Higher levels of disciplinary thinking (e.g., developing mathematical proofs or constructing original testable hypotheses) are noticeably absent from many mathematics and science classrooms.

An integration strategy /approach to the teaching of science and mathematics in integrative ways, is proposed here. This strategy, which we call problem-centering strategy, involves enlisting the knowledge and modes of thinking in two or more disciplines (e.g., science, mathematics,) to address particular problems, develop specific products, or propose a course of action. For example, a way to teach evolution in an integrative way is to present pupils with a tangible problem that could be solved with the help of some aspects of evolutionary theory. This would constitute a problem-centered approach to integrating material on evolution.

## A PROBLEM-CENTERING STRATEGY IN MATHEMATICS AND SCIENCE

Focus on a tangible and real-world problem rather than on enhancing disciplinary understanding, defines the problem-centering strategy and determines a special kind of relationship among the disciplines. Problem-based learning is the pedagogy that we tried to apply in some classrooms of our school. Problem-centering of the curriculum is applicable in different classrooms. Problem-centering can bring different fields in close interaction with one another and thus foster broad external connections between the sciences and other fields. Although problem-centered learning could be part of any classroom, some disciplines seem to be more regular and consistent users of this strategy. These tend to be science disciplines, such as biology or physics, which target a problem as the subject of their analysis. Addressing a tangible and real-world problem involves mapping the problem territory, bringing together all of the relevant disciplinary tools in order to provide a rich description of the problem, isolate its “primary issue,” and define what the solution might be. In the process of generating an answer from these various sources, pupils confront differences in perspective and have to reconcile them. Thus, the final report is a synthesis of mathematics, science and other disciplines. The advantage of this pragmatic orientation toward interdisciplinary interaction is that it brings together a wide range of disciplines.

The scientific /mathematical tools and procedures are engaged in the problem-centering approach thoroughly, if not extensively. As a result, the pupil might actually perfect his/her skill of statistical analysis or learn more about molecular weights as he/she assesses the contamination of groundwater. When mastery of disciplinary tools serves a compelling problem, significant and highly motivated learning of mathematical and scientific theories can occur. Problem-centering tends to be a transferable strategy. It offers the point of connection that provides motivation for negotiating and reconciling disciplinary differences. Science and math often find themselves as valuable partners in this conversation as they lend tools and practices for collective inquiry into a complex issue. The strengths of this strategy include: pupils' attention and creativity are fully mobilized by the urgency of the problem;  it inspires activist approach to learning and knowledge in pupils; motivation and thorough mastery of the disciplinary content (e.g., facts, practices, theories) occurs as a result; unrelated disciplines come together easily in this strategy, as differences between them are addressed decisively and pragmatically. In parallel, there are some weaknesses of the problem-centering strategy: learning is highly targeted to the problem and therefore coverage of the field is limited to relevant tools and theories only; reflection and deliberation on the discrepancies in the disciplinary approaches is minimal.

Problem-centering uses an ill-structured problem, rather than history or culture, as a point of connection between science or mathematics and any other discipline. It makes connections between ideas precise and pragmatically relevant. No investigation of broader disciplinary context of the issue or different tools is typically undertaken, nor does one typically spend much time on concept-building or deriving historical meaning from mathematical or scientific data in this model. Problem-centering, as a strategy, pursues a clearly defined goal: to resolve an urgent, tangible, and complex problem that invites or demands input from several fields. The problem-centering strategy/ approach is aimed at generating critical action. The integrative strength of this model lies in its flexibility to reach out and include a wide spectrum of disciplines as well as to encourage the mastery of disciplinary content. The blind spot of this strategy could be the pragmatic narrowness of the disciplinary exploration. Nevertheless, the motivational and integrative power of this strategy is notable.

**ICT Integration in Secondary Science and Mathematics**

The distinction between teaching ICT (or computers, or Information Technology) as a discrete subject and teaching different (other than ICT) subjects with/via the use of ICT is widely known. In this paper we refer to the latter case, and more specifically, the ICT use/ integration in science and mathematics lessons. Research findings suggest that ICT in secondary science, particularly in the form of simulations or animations of processes, provides a range of affordances for learning science (e.g., Webb & Cox, 2004). Computer science software allows pupils to visualize and understand phenomena that cannot easily be observed or allows pupils in constructing and interpreting graphs (e.g., of speed over time). For example, research showed that through using simulations pupils gained understanding of physical phenomena involving interacting variables, enabled pupils to perform at higher cognitive levels and promoted conceptual change (Jimoyiannis & Komis, 2001; Nikolopoulou, 2000). Cox and Nikolopoulou (1997) showed that computer based data analysis software helped 13-14 year old pupils to perform a range of intellectually advanced/ complex data analysis tasks, such as classifying data according to different criteria.

Regarding ICT use/ integration in secondary mathematics classrooms, there have also been research studies which provide evidence of a positive effect of ICT on pupils' attainment. Important affordances of ICT in mathematics are associated with investigations where pupils explore, conjecture, construct and explain relationships. The use of software to support exploration of quadratic functions with an open learning environment allows pupils to explore within a framework. Effective pedagogical practices in these contexts are promoting pupils' interaction with the task and with each other. For example, Jones (2002) reported that interacting with dynamic geometry systems can help pupils to explore, conjecture and explain geometrical relationships. It can provide them with the basis from which to build deductive proofs. Hennessy (2000) working with graphing, observed that the graph plotting became very simple, and the learning gains were greatest in the area of determining intercept, interpolation and finding range from a graph.

Evidence suggests that different types of ICT use provide different affordances for pupils' learning in different subject areas. We emphasize that when ICT is integrated in science or mathematics classrooms there are various factors that impact on pupils' learning such as the type of the software, the pedagogical practices, classroom interactions (e.g., collaborative learning) and the teachers' beliefs, skills and knowledge.

# THE STUDY

## Sample and Procedure

As discussed earlier this is a pilot study, as we still collect data for the main study. The authors of this paper are mathematics and physics teacher respectively and decided to integrate mathematics and physics using ICT as a tool, in two classes. Both classes held 56 pupils aged 13-14 years old (i.e. attending the 2nd year of the Greek secondary school), and the pilot study was carried out during the autumn term 2013-14. The school is a "pilot experimental" high school (pupils aged 12-15 years old) and its policy encourages teachers to apply and evaluate experimental strategies/ approaches in their classroom practices. Thus, an interdisciplinary approach to mathematics and science is positioned within the school's acceptable educational practices. We planned together and we worked on particular units of our subjects (mathematics and physics).

## Examples of Topics

Table 1 shows examples of topics which involve mathematics and physics, as well as indicative pupils' tasks and relevant corresponding mathematic learning objectives. The topics shown are indicative and these are included in the curriculum we follow in the school for pupils aged 13-14 years old. The problem-centering approach may improve pupils' motivation to learn mathematics. For example, pupils who do not enjoy learning the vectors unit (or find it useless), may start using vectors to solve geometry problems, or mechanics problems in physics – understanding better the operations with vectors. Moreover, pupils who may not like mathematics but are good at physics can see the vectors' applicability to physics and start thinking that learning maths supports them in understanding physics (e.g., velocities and forces).

**Table 1. Examples of topics which involve both mathematics and physics**

| Topic | Pupils' tasks | Mathematic learning objectives |
|---|---|---|
| Quadratic functions | - pupils watch the video of the freely falling ball experiment and use the freely falling ball graph (position depending on time)<br>- by reading the graph, pupils identify the position of the ball at different moments, the interval of time between two different positions of the ball, the domain and co-domain of the function, axes intercepts and their meaning related to the experiment, coordinates of the vertex point, monotonicity of the function, the image of the function<br>- pupils calculate the 2nd degree polynomial which defines the graphed function | - pupils interpret functions from graphs<br>- analyze quadratic functions to describe the motion of an object<br>- identify applicability of quadratic functions |
| Vectors | - pupils explain the solution of the two vectors problems (use of addition vectors tools to solve relative velocity)<br>- the problems could be available on a website proposed to pupils | - pupils use addition of vectors to solve problems in nonmathematical context<br>- identify applicability of vectors |

## Indicative Learning Activities with ICT

Figure 1 shows two screen shots from learning activities integrating mathematics with physics in a computer environment, using the "Geogebra" software. Geogebra is a DAS (Dynamic Algebra Systems) which combines dynamic manipulation of a representation (i.e., a graph) with the functionalities of a CAS (Computer Algebra System) (Noss et al., 1997). The most important tool of DAS used in the following activity was the variation tool. Graphical representations of equations such as v=S/t which is a line that passes through the origin O (0, 0). The main advantage is that when pupils manipulate the variation tool, the result leaves its traces on the screen. One problem posed to the pupils was to calculate the velocities of a hare and a turtle, as well as to determine the position of each animal on specific time (i.e., on the 5th minute). In the beginning of this activity students are asked which one of the two lines (the green or the red one) is the graph of distance (S) over time (t) with greater velocity than the other. Students using the variation tool, manipulate time as a variable "t". Then, they can see that the distance of the corresponding points on S axis increases, as time passes; which means that velocity represented by the green line is greater. They can form the assumption that the slope of the line is related with the velocity of the moving object. Thus, the relation between slope of the line and velocity help students to embody (Tall, 2004) the relation between slope of the line and ratio of proportions. Of course the next step is proving the relation using symbols of algebra.

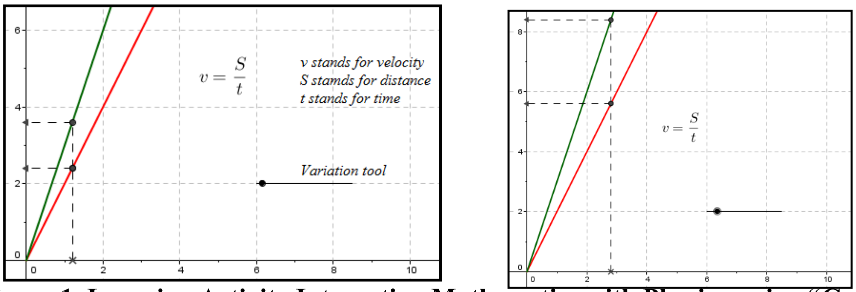


**Figure 1. Learning Activity Integrating Mathematics with Physics, using "Geogebra" Software**

## CONCLUDING REMARKS

This pilot study revealed that pupils enjoyed seeing applications of mathematics and physics in real-world problems (and this is in agreement with relevant literature). Some of the pupils, who under other circumstances were not motivated, did show increased motivation. However, this was a pilot study with several limitations. The sample was small and we did not gather data on pupils' academic achievement on accomplishing the tasks. In our main study we aim to apply the strategy to more classes, for a longer period of time, and to also collect data on pupils' perceptions and self-esteem. We aim to apply the problem-centering strategy to younger pupils (12-13 years old) studying the topic of temperature, via integrating mathematics with physics. This is an interesting topic as among the curriculum objectives are, for pupils to construct and interpret graphs of temperature versus time.

A problem-centering strategy/ approach could be extended to other school subjects, in the school. For example, mathematics and science teachers can learn from the humanities subject about the history of ideas in their fields, and focus on problems from the real world. Conversely, a problem-centering pedagogy would profit from a richer historical context. At the same time, teachers in other schools and in any subject area can benefit from keener awareness of the different frameworks that they have available to them as they design their own interdisciplinary curricula. For example, by inviting science/ mathematics and social science teachers to provide a historic context for scientific discoveries, for example, or by problem-centering of the inquiry. They will have to search for hybrid ways to build a particularly effective interdisciplinary exchange that reflects their teaching goals.

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