UNIVERSITY OF THESSALY

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Programming as a serious game for building early analytical and reasoning skills

Hariklia Tsalapatas

A dissertation submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy

Volos, 2015

ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΙΑΣ

ΠΟΛΥΤΕΧΝΙΚΗ ΣΧΟΛΗ

ΤΜΗΜΑ ΗΛΕΚΤΡΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ ΚΑΙ ΜΗΧΑΝΙΚΩΝ ΥΠΟΛΟΓΙΣΤΩΝ

Ο προγραμματισμός ως σοβαρό παιχνίδι για την ανάπτυξη αναλυτικής και αλγοριθμικής σκέψης σε παιδιά

Χαρίκλεια Τσαλαπάτα

Μια διατριβή που εκπονήθηκε για τις απαιτήσεις απονομής Διδακτορικού Διπλώματος Ειδίκευσης

Βόλος, 2015

An evaluation of programming as a serious game for building early algorithmic and reasoning skills

by

Hariklia Tsalapatas

Department of Electrical and Computer Engineering

University of Thessaly

Dissertation Approved:

Elias Houstis, Professor, University of Thessaly

____

Dissertation Supervisor

Catherine Houstis

____

Committee Member

Charalampos Karagiannidis

____

Committee Member

Anna Chronaki

____

Committee Member

Marina Papastergiou

____

Committee Member

Dimitra Evaggelou

____

Committee Member

Panagiota Tsompanopoulou

____

Committee Member

Contents

Abstract

Analytical thinking is a basic, transversal skill that helps individuals excel academically and professionally across themes, subject areas, and sectors. It is increasingly in demand by employers in the knowledge economy of today and tomorrow according to ET2020, the New Skills for New Jobs initiative, and the Digital Agenda for Europe. Important aspects of analytical thinking include the ability the think methodically, to deconstruct a problem to smaller parts, and to synthesize a viable solution; the ability to make favorable decisions with positive outcomes; and the capacity to transfer critical thinking in learning contexts to real-life situations. The above are strategy elements used by players for making advancements in game play; furthermore, they are an integral part of good practices in programming, which is an inherently structured activity that applies universal logic. This work investigates how programming games rooted in logical thinking puzzles can promote critical thinking mindsets among young learners in primary education. The work introduces a methodological learning approach based on programming games that combine active, experiential learning and collaboration in social learning loops towards building reasoning and algorithmic thinking patterns at an early age. The approach combines semi-structured exploration in aphaeretic environments that introduce only relevant information allowing learners to build intuition on potential solutions to puzzles, precise algorithmic synthesis through visual presentations of programming commands with an emphasis on logical structure rather than programming syntax, visual real-time feedback on synthesis efforts, solution comparison for exposing learners optimization aspects, and gamification elements for promoting engagement and knowledge development. The methodology was evaluated in real-life contexts at schools in Greece, the Czech Republic, and Romania with the objective of establishing how collaborative programming games deployed in the classroom promote learning engagement, scaffolding of knowledge, and collective achievement. Findings demonstrate that gamification elements in the form of rewards positively impact engagement in higher order thinking activities. Most importantly, findings show that the method of integration of programming games in learning is significant. Collaborative organization of work can enhance collective results and foster higher exercise completion rates. Direction, both by the teacher in the form of briefing and de-briefing before and after engagement and by game mechanics in the form of semi-structured exploration, visual presentation of commands, feedback, and presentation of optimal solutions, further enhances learner achievement when integrated into wider collaborative class practices. Finally, the linking of programming game themes to school curricula can promote their easier integration into school learning and, as a result, elevated learner focus on analytical thinking activities.

Περίληψη

Η αναλυτική σκέψη αναγνωρίζεται σαν μια από τις βασικές εγκάρσιες δεξιότητες που βοηθούν στις καλές επιδόσεις στην ακαδημαϊκή και επαγγελματική εξέλιξη ενός ατόμου ανεξάρτητα από τον τομέα ή και γνωστικό αντικείμενο στο οποίο επικεντρώνεται. Βρίσκεται σε συνεχώς αυξανόμενη ζήτηση από τους εργοδότες στην οικονομία της γνώσης του σήμερα και του αύριο σύμφωνα με τις πρωτοβουλίες Εκπαίδευση και Κατάρτιση 2020 (Education and Training 2020, Νέες Δεξιότητες για Νέες Δεξιότητες για Νέες Θέσεις Εργασίας (New Skills for New Jobs) της Ευρωπαϊκής Επιτροπής, και Ψηφιακή Ατζέντα για την Ευρώπη (Digital Agenda for Europe). Σημαντικές πτυχές της αναλυτικής σκέψης περιλαμβάνουν την μεθοδικότητα, την αποδόμηση ενός προβλήματος σε μικρότερα μέρη, και τη σύνδεσης μιας βιώσιμη λύσης σε δεδομένο πρόβλημα. Άλλα στοιχεία της αναλυτικής σκέψης είναι η ικανότητα λήψης αποφάσεων που οδηγούν σε θετικό αποτέλεσμα και η ικανότητα μεταβίβασης του κριτικού τρόπου σκέψης από πλαίσια μάθησης σε καταστάσεις της πραγματικής ζωής. Τα παραπάνω είναι στοιχεία στρατηγικής που εφαρμόζονται από χρήστες κατά την εξέλιξη ενός ψηφιακού, ή και άλλου, παιχνιδιού. Επιπλέον, αποτελούν αναπόσπαστο μέρος των ορθών πρακτικών στον προγραμματισμό, ο οποίος είναι μια εγγενώς δομημένη δραστηριότητα βασισμένη σε καθολική λογική. Η εργασία αυτή διερευνά το πώς παιχνίδια προγραμματισμού βασισμένα σε ασκήσεις λογικής μπορούν να προάγουν την κριτική σκέψη σε νέους μαθητές στην πρωτοβάθμια εκπαίδευση. Η εργασία εισάγει μια μεθοδολογική μαθησιακή προσέγγιση βασισμένη σε παιχνίδια προγραμματισμού που συνδυάζουν ενεργές, βιωματικές διαδικασίες και συνεργασία σε κύκλους κοινωνικής μάθησης με σκοπό την οικοδόμηση συλλογιστικής και αλγοριθμικής σκέψης σε νεαρή ηλικία. Η μέθοδος αυτή συνδυάζει ημι-δομημένη εξερεύνηση σε αφαιρετικό περιβάλλον που εισάγει μόνο σχετική με ένα πρόβλημα πληροφορία επιτρέποντας στους μαθητές να αναπτύξουν διαίσθηση σχετικά με πιθανές λύσεις, ακριβή σύνθεση αλγοριθμικής λύσης με γραφικές αναπαραστάσεις εντολών προγραμματισμού που δίνουν έμφαση στην λογική δομή και όχι στην προγραμματιστική σύνταξη, γραφική ανατροφοδότηση σε πραγματικό χρόνο σχετικά με τα αποτελέσματα της προσπάθειας σύνθεσης, σύγκριση λύσεων με σκοπό την έκθεση ενός μαθητή στην έννοια της βελτιστοποίησης, και παιγνιώδη στοιχεία (gamification) για την προώθηση της ενασχόλησης με τη μάθηση και της ανάπτυξης της γνώσης. Η μεθοδολογία αξιολογήθηκε σε πραγματικές συνθήκες μάθησης σε σχολεία στην Ελλάδα, την Τσεχία, και τη Ρουμανία με στόχο τη διερεύνηση του τρόπου με τον οποίο συνεργατικά παιχνίδια προγραμματισμού μέσα στην τάξη προωθούν την ενεργή συμμετοχή στη μάθηση, τη σταδιακή αύξηση της γνώσης (scaffolding), και τη βελτίωση των συλλογικών μαθησιακών επιτευγμάτων μιας τάξης. Τα ευρήματα δείχνουν ότι τα στοιχεία παιχνιδιού με τη μορφή της

ανταμοιβής επηρεάζουν θετικά την εμπλοκή σε δραστηριότητες αναλυτικής σκέψης. Δείχνουν επιπλέον ότι η μέθοδος της ενσωμάτωσης των παιχνιδιών προγραμματισμού στη μάθηση είναι σημαντικός. Η συνεργατική οργάνωση της εργασίας μπορεί να ενισχύσει τα συλλογικά αποτελέσματα και την προώθηση υψηλότερων ποσοστών ολοκλήρωσης μαθησιακών ασκήσεων. Η καθοδήγηση, τόσο από το δάσκαλο με τη μορφή ενημέρωσης και απολογισμού πριν και μετά την εμπλοκή σε μαθησιακά παιχνίδια όσο και από την ψηφιακή εφαρμογή με τη μορφή ημι-δομημένης εξερεύνησης, γραφικής παρουσίαση εντολών, ανατροφοδότησης, και παρουσίασης βέλτιστων λύσεων, ενισχύει περαιτέρω τη επίτευξη των μαθησιακών στόχων όταν ενταχθεί σε ευρύτερες πρακτικές συνεργασίας μέσα στην τάξη. Τέλος, η σύνδεση του θέματος ενός παιχνιδιού προγραμματισμού με το σχολικό πρόγραμμα σπουδών μπορεί να προάγει την ευκολότερη ένταξή του παιχνιδιού σε διαδικασίες μάθησης στο σχολείο με συνέπεια την αυξημένη εστίαση των μαθητών σε δραστηριότητες ανάπτυξης της αναλυτικής σκέψης.

Acknowledgements

I would like to acknowledge the teachers that I worked with for the evaluation of the deployment of programming as a serious game in real-life classroom contexts Hana Pakandlova of 6ZS Kolin, Czech Republic, Argyro Paraskeva and George Metafetzis of the 1st Primary School of Volos, Vaso Korkovelou of the 11th Primary School of Volos, and Dr. Liviu Moldovan and Ioan Konig of CETTM, Romania.

Για τον Άρη

List of figures

1. Introduction

1.1 Context

Transversal learning skills, including analytical thinking, learning-to-learn, entrepreneurial thinking, ability to collaborate, and capacity to communicate effectively, among others, are abilities that can help learners excel academically in both formal and informal settings and regardless of thematic area. School curricula typically do not address the development of soft, transversal skills, such as analytical thinking, through independently set learning goals. Rather, these skills are developed in the context of other subjects. This is probably a consequence of the purpose of school curricula, which is to define concrete knowledge on specific subjects that a learner must possess upon completing a particular educational level. In practice, teachers integrate activities towards analytical skill development in mathematics and science education through problem solving. However, the creativity of teachers and learners is evident in activities towards building analytical thinking skills that go well beyond the above traditional routes and may include critical reading, critical examination, evaluation of lessons by learners, and more [1].

Analytical thinking is not only relevant to academic pursuit. Levy and Murnane (2005) argue that analytical and non-routine skills are in steadily rising demand by employers while routine cognitive skills are on decline [2]. The New Skills for New Jobs Initiative [3] reports that ‘there is a growing demand from employers for transversal competencies, such as problem-solving and analytical skills, self-management and communication skills, linguistic skills, and more generally non-routine skills’ [3] [4]. The Digital Agenda for Europe [4] Communication on Rethinking Education states that “transversal skills such as the ability to think critically, take initiative, problem solve and work collaboratively will prepare individuals for today’s varied and unpredictable career paths”. The PISA survey, which takes place every two years and aims to evaluate education systems worldwide, introduced in 2012 in its Assessment and Analytical Framework problem solving capacity as one of the key competences for which it evaluates learner preparedness to meet the challenges of the future [5] [6] [7] [8].

Programming is an inherently analytical and precise process. The most important aspect of programming is developing an algorithm; in other words a precise, accurate solution to a problem that can be executed in a specific amount of time by following well defined steps. Synthesizing a correct algorithm involves structured thinking. By the time a learner is able to write a program that implements an algorithm she has already mentally solved the problem. Introducing a series of instructions that explains to someone else, in this case the computer that does not possess intelligence but only executes commands, how to implement an algorithm implies that the learner fully understands the underlying solution and is able to elaborate on it and to document it. Algorithmic thinking is rooted in universal logic that is present in all cultures and transcends language barriers. An educational approach that deploys algorithms towards building logical thinking is, for this reason, naturally inclusive [9] [10] [11] [12]. It can be adapted to diverse educational environments engaging learners with varying learning needs. It can be personalized in terms of content, intensity, and focus to meet individual educational goals through the appropriate selection of exercises. It can be constructively used not only for building ICT skills but also towards developing structured mind sets and analytical thinking capacity.

Despite the potential benefits of using programming as a tool for building analytical thinking skills, in many countries programming not included in formal educational curricula until late high school. Indicatively, this is the case in Greece, the Czech Republic, Sweden, and Romania [13]. Some countries, like the UK, are recently introducing programming courses as a means for bridging the gap between available and industry demanded skills especially among young adults [14] [15]. Even when programming is included in secondary education curricula it is often an elective mostly selected by students that wish to follow math, science, or technology (STEM) programs in tertiary education.

Programming is taught in schools through program suites that are formally integrated into school curricula. In Greece, programming is taught through the educational platform “Glossomatheia” which is complete tool for developing applications in a programming environment and targets learners 16-18. The tool introduces students to programming syntax through a pseudo-language. However, availability of software and services for promoting digital skills in schools is still less than adequate. The European Commission communication on Technology and Open Educational

Resources observers that ‘between 50% and 80% of students in the EU never use digital textbooks, exercise software, broadcasts/podcasts, simulations or learning games’ [14]. Recognizing the urgent need for building programming skills in order to address industry needs for skilled personnel, companies such as Microsoft® and Google® are offering funds for the development of related initiatives in school education.

Software suites for programming that target school-age learners do exist. Many of them are designed by educational or other institutions as learning tools that are, however, not integrated into formal school curricula. A well-known example is the Scratch platform [16] designed by the Lifelong Kindergarten Group [17] of MIT. The platform allows learners to ‘create stories, games, and animations’ by combining commands in a visual programming environment. The platform is based on Papert’s constructivism learning framework [18] that advocates that knowledge is built rather than memorized. Another example is the Alice Programming environment [19] developed by Carnegie Mellon University which promotes object-oriented programming and targets high school children. Lego Mindstorms®, a commercial initiative that targets boys aged 7-15 and is the result of a collaboration between the Lego® company and the Lifelong Kindergarten group, provides a platform for building constructions and then programming an attached “brick” for performing specific tasks.

The above examples demonstrate a trend to promote programming skills among young learners in school education. Most of the earlier initiatives focused on pure programming skill development and had a target audience of mathematically inclined students. However, the emerging perspectives on potential educational and professional benefits of sound logical thinking that results from working with algorithms shift attitudes and lead to initiatives, such as the ones funded by Microsoft®, towards making programming widely available to all students.

Initiatives for reaching general audiences and promoting algorithmic and analytical thinking capacity can benefit from educational approaches that promote learner engagement. The above can be achieved through “serious games”, namely virtual games that are designed for a purpose other than entertainment. The idea of deploying serious games in learning is not new; it came about when virtual games starting becoming popular in the 1970s as a natural extension of the use of games in educational contexts in general. The virtual games industry is expected to grow to $87b by 2017 overcoming the movie industry. According to research firm Gartner, gamification practices in professional training are gaining significant ground and are expected to be used in 25% of business process by 2015 [20]. The above have mobilized educational experts towards designing strategies that encourage the development of virtual games for education (serious games). Policy level initiatives are underway [21] for encouraging the further development of serious games by promoting collaboration among stakeholders, identifying requirements, and facilitating funding. Such initiatives capitalize on the broad popularity of virtual games and take advantage of the educational benefits of gamified learning processes, which include enhanced motivation and engagement through rewards, clearly defined objectives, immediate feedback that helps scaffold knowledge, and adaptable difficulty levels.

1.2 Objectives

This work evaluates how programming when deployed as a serious game in collaborative learning contexts in the classroom can contribute to the development of analytical thinking and problem solving capabilities of young learners in primary education. This is pursued through the design and validation in real-life learning contexts of a virtual learning environment that deploys programming concepts towards improving learning experiences and outcomes related to analytical and algorithmic thinking. The work explores how gamification elements integrated into programming activities including rewards, exploration, focus on puzzles, and social engagement loops contributes to learner engagement with analytical thinking processes in the longer term. The work further analyses how serious games can be more effectively integrated into learning design and classroom collaboration frameworks for maximizing their impact in achieving learning objectives.

1.3 Contribution

This work contributes both the design and the evaluation within learning experiments that engage primary education students of a gamified virtual learning environment in which programming is approached as a serious game with the objective of promoting analytical and critical thinking capacity among young learners. The cMinds visual programming suite [12] focuses on the development of analytical thinking skills, as opposed to pure programming ones, by exploiting the inherent logical processes that are part of structured programming. The environment introduces young learners to programming as a game. Learners first built an understanding on the function of basic programming constructs, namely sequential commands, conditionals, and loops. Subsequently they are exposed to logical puzzles and are asked to synthesize a solution. Examples of puzzles include pattern recognition, categorization of information, math exercises, measuring a requested volume of water by using 3 water jugs of specific capacity, identifying the heavier among otherwise identical boxes through a divide and conquer approach, and more. Synthesis takes place in two steps. First learners are exposed to an "exploration area", namely a semi-structured environment which provides the necessary blocks that a learner can drag and drop for reaching the given objective. Through this process, which does not involve programming, the learner builds intuition on a potential solution to the puzzle at hand. Once the learner has built a basic understanding on how to synthesize a solution she is asked to explain to someone else, in this case a computer depicted as a robot, how to solve the problem but constructing step-by-step a visual program.

cMinds differs from pure programming software in that it all but eliminates programming syntax by depicting commands in a visual manner. This approach encourages learners to focus on the analytical process rather than programming command structure. The learner receives immediate feedback on her efforts through an animation of the execution of her program. This allows the learner to step-by-step synthesize a viable solution by visualizing the intermediate results of her efforts. Finally, the learner is introduced to the concept of optimality through comparison of a program that executes successfully to a program that performs the least number of computational steps. Gamification elements include rewards in the simple form of a "bravo" screen that the learner sees upon successful completion of a task, difficulty levels, and badges upon completing all levels of a given puzzle. The tool is designed for classroom deployment in the context of collaborative activities as opposed to standalone use by the learner at home.

The evaluation engaged 4 groups of learners aged 10 to 12 years in Greece, the Czech Republic, and Romania. During the evaluation process the learners were exposed to the cMinds environment and were asked to solve the given logical puzzles. The organization of the classroom differed in terms of the level of collaboration among learners during engagement. In some cases learners worked individually. In others they worked in small groups of two or three. In most cases collaboration was promoted before and after engagement with the tools for understanding the problem objectives and for comparing results. The evaluation demonstrated that when used within collaborative learning classroom processes serious games based on programming can promote the capability of learners to deconstruct a problem into smaller parts, to identify clearly problem objectives, to come up with creative solutions, to identify inputs and available resources for use in problem solving, to synthesize effectively a solution, and to explain the rationale of their solution to others in the class. The work further demonstrated that when used as a game programming can be exploited to initiate young learners to advanced algorithmic thinking pathways that involve well-known problem solving frameworks to which learners would otherwise be exposed to much later in their academic careers, in late high school or tertiary education as demonstrated by their capacity to solve several difficulty levels of non-trivial logical exercises. The structured processes deployed through programming games can help learners use algorithms in broader contexts and build sound logical thinking mind sets that can help them excel academically and later professionally. The gamification elements introduced played a significant role in long-term engagement. Rewards and difficultly levels acted as motivational tools, introduced a sense of success and satisfaction, and promoted long-term engagement with analytical and problem solving processes. Semi-structured exploration, which drew elements from both the micro-worlds concept introduced by Papert and from entertainment based games allowed learners to build intuition on solutions to challenges which they later documented through visual programs. Most importantly, the work demonstrated that the way serious games are integrated into wider blended learning activities and the organization of the classroom can affect their effectiveness as a learning tool. A classroom organized in an inclusive group that engages all learners, combined with teacher mediation and direction during problem initiation and debriefing processes after game deployment led to higher achievement levels.

Future work involves the extension of the above activities through the implementation of additional learning puzzles that are linked to school curricula in STEM education and beyond. In addition, the proposed analytical thinking methodology that deploys serious games for exposing young learners to programming practices as a means for building reasoning skills can be extended to younger ages. This is possible due to the highly visual presentations of programming commands in the cMinds learning suite which may allow the exposure of younger children not fully versed in reading and writing to structured thinking mind sets. On the other hand, this work can be extended for building ICT skills for young learners thus enhancing the connection between school curricula and the world of work in light of the observation that there is high demand in the ICT sector, ICT-using sectors, and innovation related sectors that are expected to drive economic growth in the coming years on professionals with digital skills.

1.4 Organization of the thesis

Work is organized on two tangents. Section 2 of this thesis focuses on the analysis of the theoretical background related to the deployment of serious games as learning tools in wider learning contexts towards building analytical thinking skills. Section 3 focuses on the documentation of the research activity which presents the proposed serious games-based learning framework for building analytical thinking skills through programming, the evaluation of this framework with groups of learners, and the analysis of the evaluation findings. Finally, section 4 summarizes contributed results.

More specifically, the theoretical background analysis is organized as follows:

Section 2.1 presents results of research that points to the urgent need for the development of analytical and critical thinking skills as part of wider transversal skill sets that help learners excel academically independent of subject area as well as, later on in life, professionally.

Section 2.2 provides an overview and analysis of the current learning approaches that promote the development of analytical and critical thinking capacity among the target group of primary education learners.

Section 2.3 presents an overview and analysis of current practices towards building digital and programming skills in education.

Section 2.4 presents an overview of past work and initiatives that focus on the development of programming skills among young learners, including emerging theories for knowledge construction as well as specific tools based on these theories that have been developed for the promotion of digital skills.

Section 2.5 provides an overview of serious games, their learning benefits, and their application in learning processes including the presentation of specific serious game that have been developed for addressing specific learning objectives in lifelong learning contexts in sectors as diverse as school education, business education, medical training, and social inclusion.

Section 2.6 provides a discussion of emerging pedagogical frameworks that are related to serious games including experiential, active, problem-based, and inquiry-based learning.

Section 2.7 discusses the wider concept of “gamification” in learning processes, which refers to introducing gaming elements in educational contexts.

Section 2.8 presents evaluation frameworks for establishing the added value of serious games in learning contexts, including qualitative approaches, approaches for establishing the educational value of serious games, and a discussion on evaluating with children.

The research contribution section is organized as follows:

Sections 3.1 and 3.2 present a summary of what we know and describe the problem statement.

Section 3.3 describes an overview the proposed research methodology for establishing the learning value of programming games towards building analytical thinking skills.

Section 3.4 provides an overview of the cMinds visual programming suite that is used for evaluating the educational added-value of serious games that deploy programming towards building analytical thinking capacity.

Section 3.5 presents the step-by-step implementation of the proposed evaluation research methodology including the activities that took place through learner engagement.

Section 3.6 provides a presentation and analysis of evaluation activities that were carried in the context of this work by deploying the cMinds learning suite as a serious game towards building analytical thinking capacity among young learners in primary education.

The work concludes with a discussion of contributions to the literature of this thesis and on future directions towards building advanced digital literacy among young learners in-line with industry demands.

2 Theoretical background

This section presents the theoretical background of this work including a review of past related research, related outcomes, educational methodologies underpinning the proposed game-based learning framework for building analytical thinking capacity through programming, gamification practices, and methodologies designed for the evaluation of the educational added value of serious games.

2.1 Evidence on the need to enhance reasoning skills among young learners – PISA and TIMMS 2012 results

The development of analytical, critical and algorithmic thinking are transversal learning competences that can help young learners excel in all subject areas ranging from science, technology, and mathematics (STEM) to critical reading, critical examination, and evaluation of lessons. Analytical thinking is a key contributor to achieving academic goals in formal education. It can help an individual excel academically independently of subject area. In adult life, analytical and critical thinking can help an individual make sound decisions towards lifelong professional and personal development and fulfillment of goals (Tsalapatas et al 2011) [9] [10].

The importance of building STEM skills as well as transversal analytical and algorithmic thinking capacity is identified in international studies including the Program for International Student Assessment (PISA) of OECD [22] and the Trends in International Mathematics and Science (TIMMS) [23] studies.

PISA is an international study that takes place every 3 years and aims to educate education systems worldwide by testing the skills and knowledge of 15-year old students. This age has a particular significance: it is the last year of compulsory education in many educational systems; and, most importantly, a correlation has been observed between the level of achievement of students at this age and their academic and professional excellence later on in life [5] [6] [7] [8]. The PISA results report argues that poor performance in mathematics at that age significantly limits an individual’s access to better paying and more satisfying jobs [5] [6] [7] [8]. In addition, the report suggests that individuals with higher mathematics scores are more likely to be active citizens and members of society, to trust others, and to view themselves as actors and not as objects. In 2012 the study engaged approximately

510.000 students in 65 economies [24]. This group represented about 28m 15-year olds globally. Two types of questionnaires are developed for PISA: the first targets students; the second targets schools. The study is not directly linked to school curricula. Rather, it aims at documenting student knowledge, establishing the degree to which students can apply knowledge in real-life situations, and identify the degree to which they have the capacity to synthesize solutions as opposed to only reproducing information. PISA evaluates student knowledge in languages, mathematics, and science. In addition, PISA aims at collecting information on the school environment. Towards this end, the questionnaire that targets teachers includes questions on learning strategies and practices applied in their school, resources used in the classroom, and parameters that can contribute to the differentiation of student performance. The information collected through the PISA questionnaires introduces context in analyses carried out by experts and policy makers. It aims at capturing the quality/cost ration in education in countries in which the survey is carried out. To this end it documents what each country spends for education.

Specifically in relation to mathematics, PISA aims to measure an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts. This includes reasoning mathematically using mathematical concepts, procedures, facts, and tools to describe, explain, and predict phenomena [8]. This definition underscores the importance of mathematics in real life and the impact that reasoning capacity can have in a student's academic performance and later on in life. Assessment of mathematics knowledge through PISA encourages the students to formulate a problem in context into a mathematical problem, employ mathematical tools to reach a solution, interpret findings in order to put results in context, and evaluation findings within the original context of the problem. Capabilities used in the PISA 2012 assessment include communication of concepts, mathematization, i.e. being able to move between the real world and the world of mathematics, representation, which refers to being able to capture a situation or present one's work, reasoning, devising strategies for problem solving, and using symbolic, formal, and technical language and operations. Assessment results are presented using 6 levels of achievement. In level 6, which corresponds to a minimum score of 669 out of 700, students are expected to conceptualize, generalize, and utilize information based on investigation and modeling of complex situations; in level 5, which corresponds to a minimum score of 644, students are expected to be able to develop and work with models for complex situations identifying constraints and specifying assumptions; in level 4, which corresponds to a minimum score of 545, students are expected to work effectively with explicit models for concrete situations that may involve constraints or call for making assumptions; in level 3, which corresponds to a minimum score of 482, students are expected to execute clearly described procedures, including those that require sequential decisions. In level 2, which corresponds to a minimum score of 420, students are expected to interpret and recognize situations in contexts that require no more than direct inference; and in level 1, which corresponds to a minimum score of 358, students are expected to answer questions involving familiar contexts where all relevant information is present and questions are clearly defined.

The 2012 PISA survey demonstrated that only 3.3% of OECD students reach level 6, 12.6% level 5, 30.8% level 4, 54.5% level 3, 77% level 2, and 92% level 1. Figure 1 below demonstrates that in most countries only a small percentage of students reach beyond level 4. In over 30 countries the percentage of students that reach level 6 is significantly low, not exceeding 5%. Exceptions, where a higher percentage of students reach high levels in mathematical scores, indicating a higher ability to reason, are Taiwan, China, Hong Kong, and Korea.

The figure further demonstrates that in Greece the percentage of students that reach level 6 is very small and that the majority of students reach levels 2 and 3 and to a lesser degree 4. The average mathematical score of Greek students in the PISA 2012 survey was 449. The deviation between this score and the OECD average of 494 is statistically significant. Similarly in science the average score is 467 as compared to the 501 OECD average score which constitutes, again, a statistically significant difference even if the results are calibrated to take into account difference in the economy of the country as related to the economies of other OECD countries (see Figure 2).

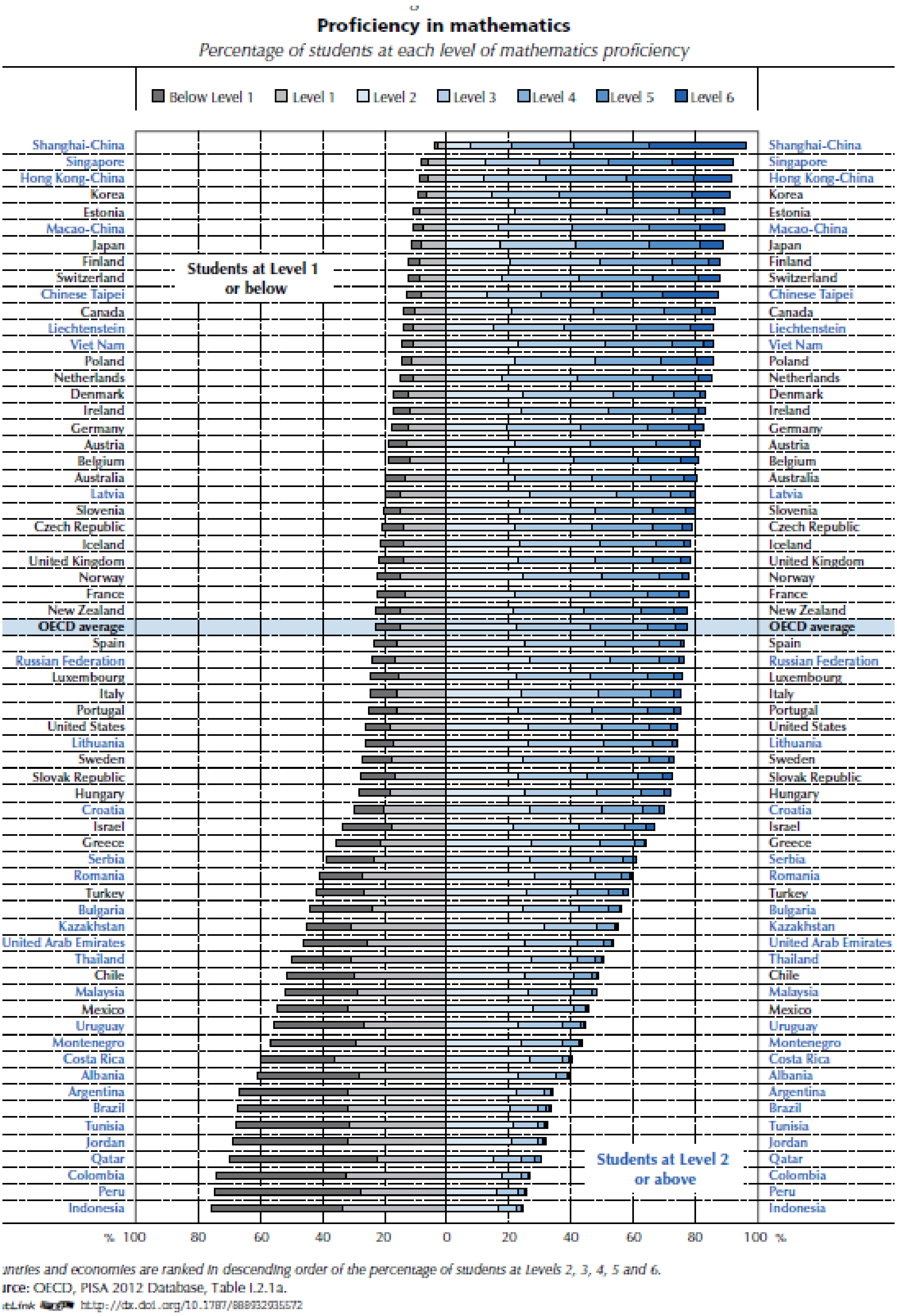


Figure 1. Percentage of students that reach each mathematical proficiency level and country as per PISA 2012 results.

Comparing countries' and economies' performance in mathematics

Statistically significantly above the OECD average
Not statistically significantly different from the OECD average
Statistically significantly below the OECD average

Mean	Comparison country/economy	Countries/economies whose mean score is NOT statistically significantly different from that comparison country's/economy's score
613	Shanghai-China	
573	Singapore	
561	Hong Kong-China	Chinese Taipei, Korea
560	Chinese Taipei	Hong Kong-China, Korea
554	Korea	Hong Kong-China, Chinese Taipei
538	Macao-China	Japan, Liechtenstein
536	Japan	Macao-China, Liechtenstein, Switzerland
535	Liechtenstein	Macao-China, Japan, Switzerland
531	Switzerland	Japan, Liechtenstein, Netherlands
523	Netherlands	Switzerland, Estonia, Finland, Canada, Poland, Viet Nam
521	Estonia	Netherlands, Finland, Canada, Poland, Viet Nam
519	Finland	Netherlands, Estonia, Canada, Poland, Belgium, Germany, Viet Nam
518	Canada	Netherlands, Estonia, Finland, Poland, Belgium, Germany, Viet Nam
518	Poland	Netherlands, Estonia, Finland, Canada, Belgium, Germany, Viet Nam
515	Belgium	Finland, Canada, Poland, Germany, Viet Nam
514	Germany	Finland, Canada, Poland, Belgium, Viet Nam
511	Viet Nam	Netherlands, Estonia, Finland, Canada, Poland, Belgium, Germany, Austria, Australia, Ireland
506	Austria	Viet Nam, Australia, Ireland, Slovenia, Denmark, New Zealand, Czech Republic
504	Australia	Viet Nam, Austria, Ireland, Slovenia, Denmark, New Zealand, Czech Republic
501	Ireland	Viet Nam, Austria, Australia, Slovenia, Denmark, New Zealand, Czech Republic, France, United Kingdom
501	Slovenia	Austria, Australia, Ireland, Denmark, New Zealand, Czech Republic
500	Denmark	Austria, Australia, Ireland, Slovenia, New Zealand, Czech Republic, France, United Kingdom
500	New Zealand	Austria, Australia, Ireland, Slovenia, Denmark, Czech Republic, France, United Kingdom
499	Czech Republic	Austria, Australia, Ireland, Slovenia, Denmark, New Zealand, France, United Kingdom, Iceland
495	France	Ireland, Denmark, New Zealand, Czech Republic, United Kingdom, Iceland, Latvia, Luxembourg, Norway, Portugal
494	United Kingdom	Ireland, Denmark, New Zealand, Czech Republic, France, Iceland, Latvia, Luxembourg, Norway, Portugal
493	Iceland	Czech Republic, France, United Kingdom, Latvia, Luxembourg, Norway, Portugal
491	Latvia	France, United Kingdom, Iceland, Luxembourg, Norway, Portugal, Italy, Spain
490	Luxembourg	France, United Kingdom, Iceland, Latvia, Norway, Portugal
489	Norway	France, United Kingdom, Iceland, Latvia, Luxembourg, Portugal, Italy, Spain, Russian Federation, Slovak Republic, United States
487	Portugal	France, United Kingdom, Iceland, Latvia, Luxembourg, Norway, Italy, Spain, Russian Federation, Slovak Republic, United States, Lithuania
485	Italy	Latvia, Norway, Portugal, Spain, Russian Federation, Slovak Republic, United States, Lithuania
484	Spain	Latvia, Norway, Portugal, Italy, Russian Federation, Slovak Republic, United States, Lithuania, Hungary
482	Russian Federation	Norway, Portugal, Italy, Spain, Slovak Republic, United States, Lithuania, Sweden, Hungary
482	Slovak Republic	Norway, Portugal, Italy, Spain, Russian Federation, United States, Lithuania, Sweden, Hungary
481	United States	Norway, Portugal, Italy, Spain, Russian Federation, Slovak Republic, Lithuania, Sweden, Hungary
479	Lithuania	Portugal, Italy, Spain, Russian Federation, Slovak Republic, United States, Sweden, Hungary, Croatia
478	Sweden	Russian Federation, Slovak Republic, United States, Lithuania, Hungary, Croatia
477	Hungary	Spain, Russian Federation, Slovak Republic, United States, Lithuania, Sweden, Croatia, Israel
471	Croatia	Lithuania, Sweden, Hungary, Israel
466	Israel	Hungary, Croatia
453	Greece	Serbia, Turkey, Romania
449	Serbia	Greece, Turkey, Romania, Bulgaria
448	Turkey	Greece, Serbia, Romania, Cyprus[1,2], Bulgaria
445	Romania	Greece, Serbia, Turkey, Cyprus[1,2], Bulgaria
440	Cyprus[1,2]	Turkey, Romania, Bulgaria
439	Bulgaria	Serbia, Turkey, Romania, Cyprus[1,2], United Arab Emirates, Kazakhstan
434	United Arab Emirates	Bulgaria, Kazakhstan, Thailand
432	Kazakhstan	Bulgaria, United Arab Emirates, Thailand
427	Thailand	United Arab Emirates, Kazakhstan, Chile, Malaysia
423	Chile	Thailand, Malaysia
421	Malaysia	Thailand, Chile
413	Mexico	Uruguay, Costa Rica
410	Montenegro	Uruguay, Costa Rica
409	Uruguay	Mexico, Montenegro, Costa Rica
407	Costa Rica	Mexico, Montenegro, Uruguay
394	Albania	Brazil, Argentina, Tunisia
391	Brazil	Albania, Argentina, Tunisia, Jordan
388	Argentina	Albania, Brazil, Tunisia, Jordan
388	Tunisia	Albania, Brazil, Argentina, Jordan
386	Jordan	Brazil, Argentina, Tunisia
376	Colombia	Qatar, Indonesia, Peru
376	Qatar	Colombia, Indonesia
375	Indonesia	Colombia, Qatar, Peru
368	Peru	Colombia, Indonesia

Footnote by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkis
d Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context c
e United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

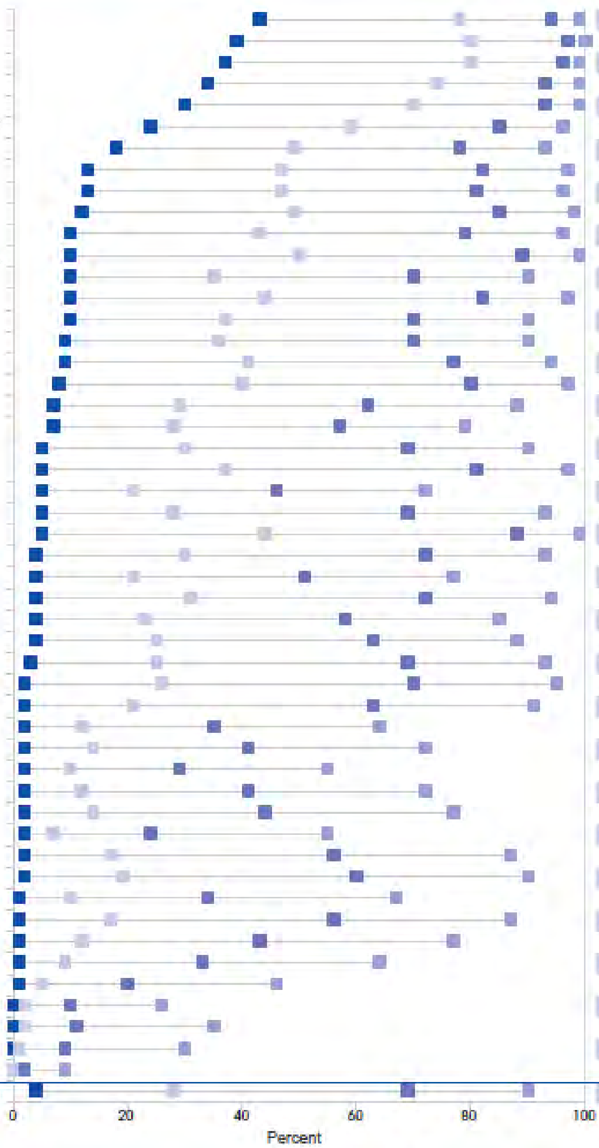
Footnote by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with th
ception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

ountries and economies are ranked in descending order of the mean mathematics score in PISA 2012.

urce: OECD, PISA 2012 Database; Figure I.2.13.

Figure 2. Comparing countries' and economies' performance in mathematics, source PISA 2012.

TIMMS is a study that is conducted by the US National Center for Educational Statistics. It focuses on 4th and 8th graders and aims at establishing the knowledge of students on mathematics and science knowledge. In 2011 the survey was carried out in 60 countries, including the US [23] [25]. Contrary to PISA, TIMMS does align broadly with mathematical and science curricula in participating countries. It further collects background information on students, teachers, schools, curricula, and education policies to allow cross national comparison of educational contexts [26]. In absolute numbers the TIMMS scale has a high score of 700. TIMMS has established international benchmarks that help understand variations in student achievement. For mathematics grade 4 advanced level, corresponding to 625 points, reflects the fact that students can apply their understanding and knowledge and explain their reasoning; high level, corresponding to 550 points, reflects the fact that students can apply their knowledge and understanding in solving problems; intermediate level, corresponding to 475 points, reflects the fact students can apply basic mathematical knowledge in straightforward situations; and low level, corresponding to 400 points, reflects the fact that students have some basic mathematical knowledge. For mathematics grade 8 advanced level reflects the fact that students can reason with information, draw conclusions, make generalizations, and solve linear equations; high level reflects the fact that students can apply their knowledge and understanding in a variety of complex situations; intermediate level reflects the fact students can apply basic mathematical knowledge in straightforward situations; and low level reflects the fact that students have some knowledge on whole numbers and decimals, operations, and basic graphs. TIMMS further demonstrates that in mathematics only a small percentage of students reach the advanced level demonstrating the ability to reason. This observation is made for students in the fourth grade (see Figure 3 below). The figure demonstrates that in a few countries, such as Singapore, The Republic of Korea, Hong Kong, Taiwan, and Japan, do over 30% of students reach the advanced level. In at least 28 of the participating countries the percentage of students that reaches the advanced level is 5% or below.



Education system	Advanced (625)	High (550)	Intermediate (475)	Low (400)
Singapore[1]	43 *	78 *	94 *	99 *
Korea, Rep. of	39 *	80 *	97 *	100 *
Hong Kong-CHN[1]	37 *	80 *	96 *	99 *
Chinese Taipei-CHN	34 *	74 *	93 *	99 *
Japan	30 *	70 *	93 *	99 *
Northern Ireland-GBR[2]	24 *	59 *	85 *	96
England-GBR	18 *	49	78 *	93 *
Russian Federation	13	47	82	97
United States[1]	**13**	**47**	**81**	**96**
Finland	12	49	85 *	98 *
Lithuania[1,3]	10 *	43 *	79	96
Belgium (Flemish)-BEL	10 *	50	89 *	99 *
Australia	10 *	35 *	70 *	90 *
Denmark[1]	10 *	44	82	97
Hungary	10 *	37 *	70 *	90 *
Serbia[1]	9 *	36 *	70 *	90 *
Ireland	9 *	41 *	77 *	94 *
Portugal	8 *	40 *	80	97
Kazakhstan[1]	7 *	29 *	62 *	88 *
Romania	7 *	28 *	57 *	79 *
Slovak Republic	5 *	30 *	69 *	90 *
Germany	5 *	37 *	81	97
Azerbaijan[1,4]	5 *	21 *	46 *	72 *
Italy	5 *	28 *	69 *	93 *
Netherlands[2]	5 *	44	88 *	99 *
Czech Republic	4 *	30 *	72 *	93 *
Turkey	4 *	21 *	51 *	77 *
Slovenia	4 *	31 *	72 *	94 *
New Zealand	4 *	23 *	58 *	85 *
Malta	4 *	25 *	63 *	88 *
Sweden	3 *	25 *	69 *	93 *
Austria	2 *	26 *	70 *	95
Norway[5]	2 *	21 *	63 *	91 *
United Arab Emirates	2 *	12 *	35 *	64 *
Armenia	2 *	14 *	41 *	72 *
Qatar[1]	2 *	10 *	29 *	55 *
Georgia[3,4]	2 *	12 *	41 *	72 *
Chile	2 *	14 *	44 *	77 *
Saudi Arabia	2 *	7 *	24 *	55 *
Poland	2 *	17 *	56 *	87 *
Croatia[1]	2 *	19 *	60 *	90 *
Bahrain	1 *	10 *	34 *	67 *
Spain	1 *	17 *	56 *	87 *
Thailand	1 *	12 *	43 *	77 *
Iran, Islamic Rep. of	1 *	9 *	33 *	64 *
Oman[5]	1 *	5 *	20 *	46 *
Morocco[7]	# *	2 *	10 *	26 *
Kuwait[3,7]	# *	2 *	11 *	35 *
Yemen[7]	# *	1 *	9 *	30 *
Tunisia[5]	# *	# *	2 *	9 *
International Median	4 *	28 *	69 *	90 *

Percentage of students reaching each international benchmark

Figure 3. TIMMS 2011 fourth grades' scores in mathematics, source International Association for the Evaluation of Educational Achievement.

Similar findings are observed in eighth graders (see Figure 4 below) with the countries that perform well or not so well being approximately the same. This demonstrates that some educational systems are a lot more successful in building reasoning skills among young learners than others.

The above discussion on PISA and TIMMS data analysis suggest the need for learning interventions towards enhancing analytical and critical reasoning among primary and lower secondary students. The studies conclude that it is important to address the needs of diverging population towards narrowing the gap in student performance, taking into account that even within the same country deviations in scores can reach 300 points. This, however, remains a formidable challenge.

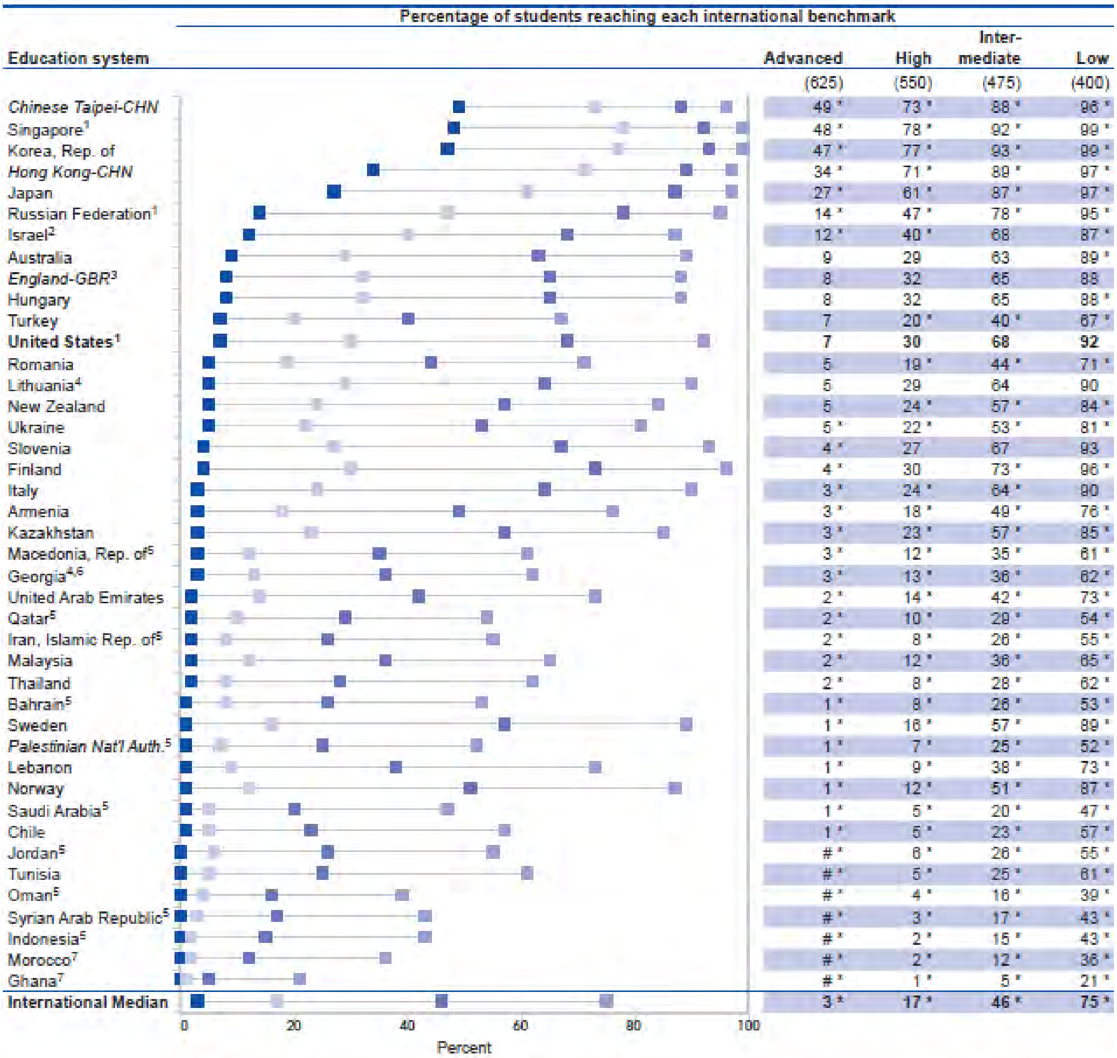


Figure 4. TIMMS 2011 eighth grades' scores in mathematics, source International Association for the Evaluation of Educational Achievement.

In many countries, logical thinking is not directly addressed by school curricula; this is possibly a result of the focus of curricula on knowledge that learners must have upon completing a specific educational level, for example primary education, as opposed to skills, especially soft, transversal ones.

Teachers however recognize the importance of analytical and logical thinking and develop learning activities for building the skill in the context of varied curricula subjects [13]. These activities are often delivered in the classroom off-line, without the use of digital aids, and can span thematic areas as broad as literature, the environment, and of course mathematical education.

However, teachers in the field in countries as diverse as Greece, the Czech Republic, Sweden, and Romania point to the need of teaching support tools, especially in digital form, for supporting their instructional efforts (Tsalapatas et al) [11].

Programming is an inherently structured activity that helps learners build problem solving and analytical skills. This is achieved through the inherently structured nature of programming. Algorithmic thinking, which is the core focus of programming activities, encourages learners to conceive high level solutions to a given problem, deconstruct an algorithm in smaller parts, and implementing precise solutions to those contained steps. This algorithm conception and design process is very close to analytical thinking which involves the identification of problem objectives, the recognition of input data, the deconstruction of a problem, and the development of a solution through the integration of smaller parts. Algorithmic thinking and programming reach beyond cultural and language barriers; they are universal in nature making them potentially good candidates as tools towards the development of logical skills among young learners.

This work presents an evaluation framework for validating the added value of programming games in the context of building logical thinking skills among primary education learners. In the context of this work logical thinking is defined as follows: the ability to recognize problem objectives; to state assumptions and document input data; to synthesize a logical solution to a given puzzle; to understand the solution thoroughly and be able to explain it to a peer.

Evaluation is pursued by use of the cMinds serious programming game [12] which was developed in the context of a multi-national project completed in November 2012. The cMinds game asks learners to introduce precise and structured visual programming solutions to logical puzzles. The game applies constructivist learning approaches by presenting logical exercises in the form of ‘microworlds’, which are contained simulations of the real world that provide enough information for encourage problem exploration while avoiding unnecessary “noise”. Initially, the game exposes learners to common programming structures such as loops, conditionals, and switches through a tutorial area in which they are called to instruct a robot, i.e. a humanlike representation of a computer, to collect apples from an apple tree based on restrictions and rules. Once learners develop a working command of these constructs they are asked to apply them towards synthesizing solutions to logical puzzles. Solution synthesis is developed in steps: learners are presented with the problem data; they are encouraged to explore potential solutions through a semi-structured exploration environment; they are asked to build a precise visual algorithm by dragging and dropping commands from a toolset into a programming zone; finally they are encouraged to compare their solution to an "optimal" one pre-built into the environment, becoming aware of optimization processes.

2.1 The current situation in learning approaches towards building analytical and problem-solving skills in school education

The development of soft and transversal skills including learning-to-learn, analytical and critical thinking, entrepreneurial thinking or thinking out of the box, ability to collaborate, is today highly relevant. Research demonstrates that there is a shift in the job market from the demand of routine cognitive skills to non-routine analytical ones. This is demonstrated in the following graph by David Autor, Frank Levy, and Richard Murnane (2003) [2].

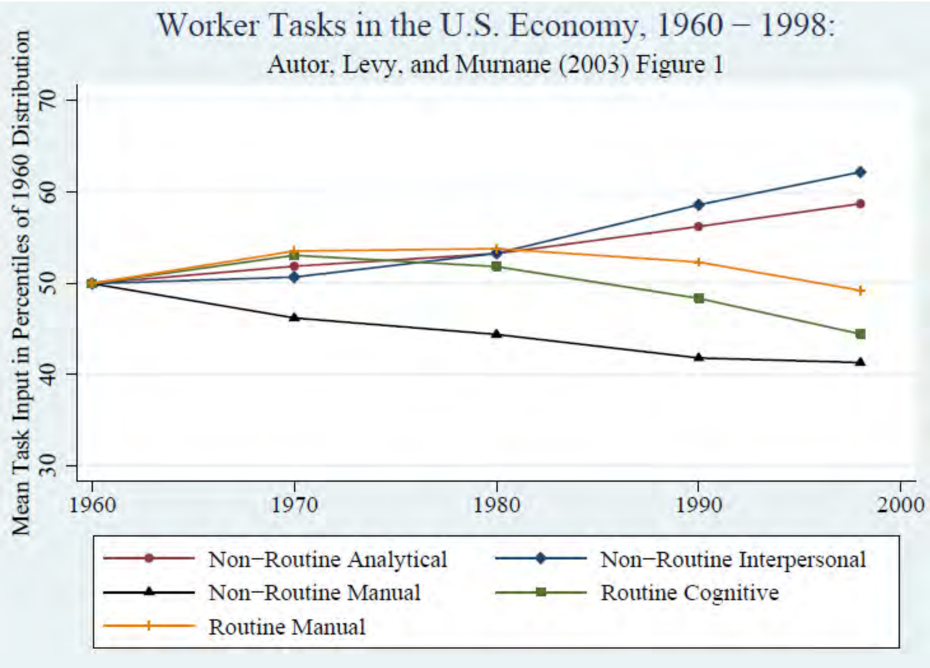


Figure 5. The shift on demand from routine cognitive to non-routine analytical skills in the job market (Autor, Levy, and Murnane, 2003).

The importance of analytical thinking and problem solving capacity of young learners has led the organizers of the PISA survey to include problem solving in the set of skills under focus in the 2012 cycle [27]. In the PISA 2012 framework publication

(OECD, 2013b) problem solving competence is discussed as a set of key elements that include '… an individual's capacity to engage in cognitive processing to understand and solve problem situations'. Other features of the PISA problem solving framework include understanding the nature of the problem situation, which can be either static with all information being presented or interactive with not all information being disclosed; the problem context, namely the everyday scenario in which the problem is embedded, and the problem solving process, namely the main cognitive processes involved in resolving a specific task. The PISA survey focuses on the following cognitive processes: exploring and understanding a problem by observing it, interacting with it, and searching for information; representing and formulating a problem through graphs, tables, symbols, and words; planning and executing a path for solving the problem at hand; and finally monitoring and reflecting on the problem solution.

Key findings of the survey demonstrated that students from Singapore and Korea, followed by students from Japan, scored the highest. On average across all OECD countries about 20% of students is able to solve only very straightforward problems. About 11.4% of students are top performers, meaning that they can systematically explore complex problem scenarios. Furthermore, the results demonstrate that problem solving performance is related to performance in other subject areas.

Despite the importance of analytical thinking and problem solving skills these, similarly to other soft, transversal skills, are not directly addressed by formal school curricula. This may be partly due to the nature and objective of school curricula that aim at establishing the knowledge that a student must demonstrate to possess upon completing a specific grade in formal education [13]. In some countries curricula do set goals in relation to building analytical thinking capacity. For example, in Sweden the current curriculum (Lpo94) [13] defines as educational goals 'the strengthening of the ability to independently formulate viewpoints based not only on knowledge but also on rational and ethical considerations' and 'learning to listen, discuss, reason, and use knowledge as a tool for formulating and evaluation assumptions, solving problems, reflecting on experiences, and critically examining statements and relationships'.

■ Figure V.2.3 ■

Comparing countries' and economies' performance in problem solving

Statistically significantly **above** the OECD average
Not statistically significantly different from the OECD average
Statistically significantly **below** the OECD average

Mean score	Comparison country/economy	Countries and economies whose mean score is NOT statistically significantly different from the comparison country's/economy's score
562	Singapore	Korea
561	Korea	Singapore, Japan
552	Japan	Korea
540	Macao-China	Hong Kong-China, Shanghai-China
540	Hong Kong-China	Macao-China, Shanghai-China, Chinese Taipei
536	Shanghai-China	Macao-China, Hong Kong-China, Chinese Taipei
534	Chinese Taipei	Hong Kong-China, Shanghai-China
526	Canada	Australia, Finland, England (UK)
523	Australia	Canada, Finland, England (UK)
523	Finland	Canada, Australia, England (UK)
517	England (UK)	Canada, Australia, Finland, Estonia, France, Netherlands, Italy, Czech Republic, Germany, United States, Belgium, Austria
515	Estonia	England (UK), France, Netherlands, Italy, Czech Republic, Germany, United States
511	France	England (UK), Estonia, Netherlands, Italy, Czech Republic, Germany, United States, Belgium, Austria, Norway
511	Netherlands	England (UK), Estonia, France, Italy, Czech Republic, Germany, United States, Belgium, Austria, Norway
510	Italy	England (UK), Estonia, France, Netherlands, Czech Republic, Germany, United States, Belgium, Austria, Norway
509	Czech Republic	England (UK), Estonia, France, Netherlands, Italy, Germany, United States, Belgium, Austria, Norway
509	Germany	England (UK), Estonia, France, Netherlands, Italy, Czech Republic, United States, Belgium, Austria, Norway
508	United States	England (UK), Estonia, France, Netherlands, Italy, Czech Republic, Germany, Belgium, Austria, Norway, Ireland
508	Belgium	England (UK), France, Netherlands, Italy, Czech Republic, Germany, United States, Austria, Norway
506	Austria	England (UK), France, Netherlands, Italy, Czech Republic, Germany, United States, Belgium, Norway, Ireland
503	Norway	France, Netherlands, Italy, Czech Republic, Germany, United States, Belgium, Austria, Ireland, Denmark, Portugal
498	Ireland	United States, Austria, Norway, Denmark, Portugal, Sweden
497	Denmark	Norway, Ireland, Portugal, Sweden, Russian Federation
494	Portugal	Norway, Ireland, Denmark, Sweden, Russian Federation
491	Sweden	Ireland, Denmark, Portugal, Russian Federation, Slovak Republic, Poland
489	Russian Federation	Denmark, Portugal, Sweden, Slovak Republic, Poland
483	Slovak Republic	Sweden, Russian Federation, Poland, Spain, Slovenia
481	Poland	Sweden, Russian Federation, Slovak Republic, Spain, Slovenia, Serbia
477	Spain	Slovak Republic, Poland, Slovenia, Serbia, Croatia
476	Slovenia	Slovak Republic, Poland, Spain, Serbia
473	Serbia	Poland, Spain, Slovenia, Croatia
466	Croatia	Spain, Serbia, Hungary, Israel
459	Hungary	Croatia, Turkey, Israel
454	Turkey	Hungary, Israel, Chile
454	Israel	Croatia, Hungary, Turkey, Chile, Cyprus[1, 2]
448	Chile	Turkey, Israel, Cyprus[1, 2]
445	Cyprus[1, 2]	Israel, Chile
428	Brazil	Malaysia
422	Malaysia	Brazil
411	United Arab Emirates	Montenegro, Uruguay, Bulgaria
407	Montenegro	United Arab Emirates, Uruguay, Bulgaria
403	Uruguay	United Arab Emirates, Montenegro, Bulgaria, Colombia
402	Bulgaria	United Arab Emirates, Montenegro, Uruguay, Colombia
399	Colombia	Uruguay, Bulgaria

. Footnote by Turkey: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority epresenting both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and quitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".
. Footnote by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the Jnited Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.
ource: OECD, PISA 2012 Database.
StatLink http://dx.doi.org/10.1787/888933003573

Figure 6. PISA 2012 results of problem solving capacity of 15 year olds.

Analytical thinking skills are often addressed in the context of other curricula subjects. Given the lack of formal educational activities for the development of analytical thinking skills teachers often design activities for implementation in classrooms. These activities do not only span the more intuitive thematic areas of

STEM education; they may spread in diverse subject areas that go well beyond mathematics and science.

Examples of activities related to the development of analytical thinking capacity proposed by teachers in Greece, the Czech Republic, Romania, and Norway include [13]:

- Making predictions
- Comparing, critiquing, investigating, and categorizing,
- Solving mathematical exercises; critically examining assumptions, limitations, and application of solutions in different contexts
- Looking at the big picture of a given scenario, identifying the current situation, identifying goals
- Critical reading: understanding important pints in texts as well as concepts, messages, and data in diverse thematic areas
- Role playing in which learners are asked to provide solutions for case studies and hypothetical situations
- Recognizing diverging viewpoints and solution paths and thinking innovatively; compare solutions introduced by different class members
- Solve problems linked to everyday life
- Evaluation lessons and themes
- Solve multidisciplinary, non-trivial assignments deploying knowledge in diverse subject areas
- And more

The above demonstrate ways in which teachers pursue the development of analytical thinking skills through activities that span the school curriculum. Introducing analytical thinking processes into learning practices is considered by teachers as a desirable learning approach that enriches school practices. Analytical thinking is currently practiced mostly through off-line activities without the support of digital tools [13]. This is the result of a significant lack of educational tools that can be used in the classroom. In fact, teachers point to the urgent need for digital learning applications that can enrich existing classroom practices.

2.3 The current situation on the development of digital and programming skills in school education

The development of digital skills is today highly relevant. According to the Grand Coalition for Digital Jobs [28] in the coming decade there will be a shortage of as many as 900.000 professionals in the ICT sector or ICT-using sectors. In addition, the same initiative observes that for every ICT job that is created five additional jobs will be created in other sectors. In other words, the capacity to work effectively with emerging ICT technology not only in the ICT industry but in diverse economic sectors that deploy ICT services and tools for promoting business development, productivity, and growth is becoming of strategic importance. Furthermore, innovation-related sectors are expected to drive economic growth in the near future according to the Digital Agenda for Europe [4].

In this economic environment, effective ICT skills of individuals will contribute to increasing their professional options making them more competitive in a global job market. For companies, including SMEs, advanced collective ICT skill sets of staff will contribute to capacity to pursue effectively emerging business opportunities.

The New Skills for New Jobs Initiative [3] identifies digital skills as core, basic competencies to which priority is given in the context of Education and Training (ET2020) and other educational and development strategic initiatives.

This broad recognition on the importance of developing digital skills with an emphasis on the next generation is not yet reflected in school curricula in many countries.

In Greece, programming skill development is an elective in the final years of secondary education. While programming is in school curricula in earlier grades, even in primary school, the number of hours foreseen for this activity is very limited, as low as 10-12 hours per school year, resulting in the students being only very briefly to programming concepts. The elective is typically opted for by students that wish to pursue a career in computer science or engineering. As a result, a large percentage of students do not get exposed to courses that promote the development of programming skills.

The teaching of programming in Greek secondary schools is supported by the educational platform Glossomatheia, which is a complete tool for developing applications in a programming environment. The environment has the appearance of a typical programming tool. It includes a toolset of programming commands, a programming area in which the student introduces commands, a compiler, and program execution visualization.

The platform is developed for young learners aged 16-18. It deploys pseudo-code, as opposed to an actual programming language. The pseudo-code approach helps expose students to typical programming language structure. In addition, students get exposed to the logic of structuring a program in the form of flow-charts. Following the exposure to pseudo-code, the students gain capacity to effectively build programming skills in actual programming languages. This activity, however, takes place only in tertiary education in the context of computer science or engineering study programs.

For younger children formal education on digital literacy in Greece revolves around the understanding of the basic functionality of a computer from the point of view of a user. In addition, it involves the deployment of popular tools for executing projects for diverse courses. Similar approaches to digital skill development in primary education are followed in other European countries, including Sweden, Norway, and the Czech Republic [13].

However, over the past few years there is a shift on perceptions related to how school curricula should be organized for the development of digital skills among primary education learners. Interestingly, related initiatives are often led by industry players, possibly rooted to the argument made above in relation to the expected high demand for ICT professionals for ensuring sustainable business growth and the observed gap between available and needed skills in the workforce. An example is the Microsoft® Partners in Learning Network initiative [29]. The network aims at building a community of teachers for sharing ideas on the development of digital skills, publishing good practices on the deployment of technology in the classroom, and promoting innovation in teacher and learning. In addition, it provides access to free tutorials mostly in relation to the deployment of the company’s products in educational settings. Similar initiatives are offered by other industry players, such as Google(2) with its Google for Education platform [30] that targets educators and promotes the development of a community of teachers for knowledge, know-how, information and good practice exchange related to the integration of ICT solutions into educational settings.

On the other hand, some countries have already begun to revamp school curricula for more effectively building the digital skills of young learners. An example is the new computing curriculum at the UK. The curriculum is designed for learners aged 5 to 14 years and goes well beyond the development of end-user skills for ICT services and tools. Rather, the curriculum aims at the development of programming skills. The curriculum is organized in 3 key stages. Key stage 1 targets learners 5-6 years old and exposes learners to the concept of algorithms. This does not necessary take place through the use of computers; for example, teachers may illustrate the idea through recipes. Children learn to 'create, organize, store, manipulate, and retrieve digital content' [31]. Key stage 2 targets learners 7-11 years old and exposes them to the creation and debugging of more complex programs introducing concepts such as variables as well as 'sequences, selection, and repetition' in programs. Key stage 3 targets learners aged 11-14 years. The objective at this stage is to ensure that learners can effectively use two or more programming languages 'at least one of which is textual' to create their own programs [31].

Other countries demonstrate intent to introduce programming courses in schools. This includes Singapore. The Infocomm Development Authority of Singapore (IDA), a government agency in charge of the country's internet industry announced plans in 2014 to introduce a programming curriculum in schools with the objective of boosting the country's economy through the skillsets necessary among professionals. However, it is not yet clear if the topic will become part of the formal curriculum or it will be an extra curricula activity [32].

While the above demonstrate that while there is an emerging trend on the wider availability of programming courses for younger learners a lot still needs to be done towards the actual integration of end-to-end learning activities in formal school curricula.

2.4 Existing work on building programming skills among primary and lower secondary school learners

This section provides a description and discussion of existing work related to the development of programming and / or analytical skills among young learners of primary and lower secondary education school age.

2.4.1 Seymour Papert's constructivism theory and the concept of "microworlds"

Seymour Papert introduced programming as a means for building structural and analytical thinking skills among young learners. Papert was born in South Africa in 1928. He is a mathematician and computer scientist. He established the MIT Architecture Machine Group, which now has evolved into the MIT Media Lab. Before becoming engaged at MIT Paper worked at the St John's College at Cambridge, the Henri Poincare Institute of the University of Paris, the University of Geneva, and the National Physical Laboratory of London. He is a pioneer in artificial intelligence. In 2006 he had a famous accident in Hanoi, after which applied his own theories on personal development towards helping himself recover and becoming active again [33].

His pedagogical theory is based around the basic concept that a child can get a sense of control through modern technology. Through technology a child can build knowledge actively, by doing, and by acting on feedback.

Papert's main work was on "constructionism", which advocates that learners build models with the objective of understanding the world around them. Papert believes that knowledge is built and not transferred. His theory extends the "constructivism" concept introduced by Piaget, who was Papert's mentor at the University of Geneva.

Piaget was a psychologist who focused on the ways children learn. He pioneered IQ testing. During his research on developing IQ tests he observed that young learners consistently gave the wrong answer to specific questions while older learners answered the same questions correctly. This observation led to Piaget working closely with the concept of cognition and cognitive development. He concluded that at different ages an individual demonstrates specific skills. Piaget advocated that the thinking pathways of children are significantly different from those of adults. His research included elements of sociological development, biological development, analytical thinking development, and abstract thinking development.

According to his developmental stage theory humans build intelligence and logical reasoning in steps. Cognitive development is a progressive reorganization process and is affected by biological development and experience built on the surrounding world. He argued that the development process involves states and transformations. When an individual moves to a different developmental state she deconstructs and reconstructs the basic understanding of the surrounding world. The individual develops a new perception of the world.

Piaget identified 4 main developmental stages [34]:

- The sensormotor stage corresponds to ages 0-2. During this stage a child builds her understanding of the world through the senses.
- The preoperational stage corresponds to ages 2-7. In this stage a child believes in “magical thinking”. In other words, a child accepts observations of how the world works without using logic to explain phenomena.
- The operational stage corresponds to ages 7-11. In this stage a child starts applying logical reasoning.

  The formal operational stage corresponds to ages 11-16. In this stage a child develops abstract thinking.

Piaget’s work is documented in his books Genetic Epistemology and the Central Problem of Intellectual Development.

Papert (1993) applied this theory in practice by introducing the concept of “microworlds” [18] [35] [36]. In his definition microworlds simulate the real world in a virtual environment. They are simple and neutral with the objective of avoiding references to technology. The main objective of microworlds is to introduce learners to problem solving techniques. The learner can control the microworld giving commands and interacting with objects with the purpose of solving a specific puzzle and building analytical thinking capacity. By exploring in a microworld the learner can develop understanding on abstract notions actively, by doing. Furthermore, the experience the learner develops allows the transfer of knowledge and developed skills from the microworld to the real world.

A microworld presents the user with enough information for solving a problem but avoid any unnecessary “noise”, namely information that is not relevant to the problem solution. In terms of implementation a microworld contains:

- Objects
- Relationships among objects
- Functions that influence objects by altering relationships and building new objects

A microworld includes few commands. Through abstraction and a contained set of rules it helps a child focus on a problem solution and develop problem solving skills. A microworld introduces a learners into a virtual environment in which the learner is called to solve a particular problem through the use of specific tools and the interaction with entities. It supports the learning process through the provision of information and rules of operation but does not control it. The learner drives learning by being empowered to explore and experiment building experience and knowledge.

The best designed microworlds introduce a limited and well thought set of commands that can be used by learners in meaningful ways to help them understand hidden concepts. According to Papert microworlds offer the possibility of learning through exploration in a virtual world. They can offer learning alternatives in cases when exploration might not be possible otherwise, for example in the physical world. As described above microworlds are simple; however, the must be rich enough to allow the development of constructive thinking.

Other definitions of microworlds have been provided by researchers. Wilson (1995) [37] classified microworlds as “learning environments” or a “classroom metaphor” in which instruction emphasizes the “place” and “space” where learning occurs. According to Wilson a learning environment involves at the minimum the learner and the space in which the learner acts; the latter is defined as a collection of tools and devices with which the learner interacts and collects information. This definition implies a degree of initiative on behalf of the learner. It further implies that the learner is allowed to take initiative and drive learning by determining learning goals and activities. It further agrees with Papert’s proposition that the teacher should introduce the learner to the microworld but not to the information or knowledge that the learner may discover. The latter is left to the learner who is encouraged to be creative and build knowledge through exploration.

Clements (1989) [38] defines a microworld as “a small playground of the mind”. Rieber (1996, 2001) [39] [40] associate microworlds with serious play for driving learner motivation and learning by building through digital tools.

The first famous microworld introduced by Papert was the “turtle”. The learner was called to move the turtle around the space of the microworld using given commands. The purpose of this microworld was not so much to build programming knowledge but to enable learners to grasp geometry concepts through experimentation and active learning. The learner was urged to think like the turtle and to explore the microworlds' space through movement. Specifically, the turtle microworld included the following elements: the location of the turtle, the direction of movement, and a "pen". Commands allowed moving the turtle forward, backward, left, and right. In addition, commands were available for "pen up" and "pen down" allowing the tracking of the trajectory of the turtle's movement.

The microworld of the turtle led to the definition of the term "turtle graphics", which is a method of programming vector graphics using a cursor, i.e. the turtle [41].

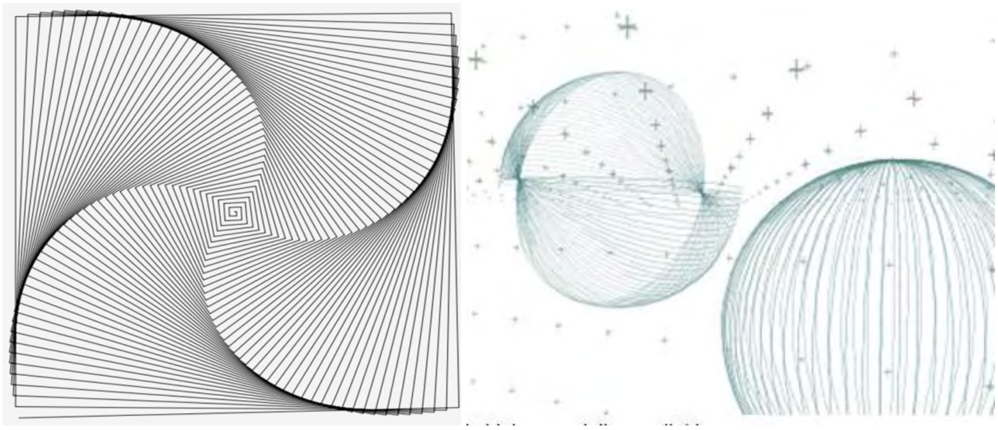


Figure 7. 2 and 3-D vector graphics.

2.4.2 The LOGO programming language

Papert developed the LOGO programming language. In line with his constructivism theory LOGO aims at building logical thinking among young children. Logo applies experiential learning, i.e. building knowledge by doing and acting in microworlds. In addition, it builds problem-based learning capacity among young learners.

Logo is a functional language. It involves numbers, words, lists, lists of lists, and functions. It further introduces the concepts of local and global variables, recursion, and debugging. The learning paradigm introduced by LOGO involves the identification of input parameters, the deconstruction of a problem in smaller ones, the development of functions, the generalization of a given problem, the synthesis of a solution to the problem, and debugging of the proposed solution [42].

Several programming environments exist for programming in LOGO and applying the concept of microworld exploration. The most commonly known are MicroWorlds Pro

[43] and the newer MicroWorlds EX [44], Kinderlogo [45], which targets young learners, and more.

The pedagogical goal of the LOGO programming language is to contribute to the development of problem solving skills among young learners through the identification of input parameters, the deconstruction of a problem into sub-problems, the construction of functions, the generalization of a problem, the synthesis of a solutions, and the process of debugging.

2.4.3 Michael Resnick's Life Long Kindergarten

Michael Resnick is a student of Papert's. He applied Papert's constructivism idea in practice by developing with his group, the Lifelong Kindergarten [17] at the MIT Media Lab [46], new technologies for engaging individuals, in particular young children, in creative learning. The name of the Lifelong Kindergarten Group is a direct reference to the simple but true notion that adults would benefit from learning like young children do, through hands-on experimentation. Resnick argues that children learn by trial and error; he further argues that active learning approaches that are deployed by children spontaneously may offer learning advantages to broader learner groups, such as adults engaged in lifelong skill building activities.

Resnick observes that today's school system does not focus on building creative thinking among young learners despite the fact that a creative mindset is a powerful tool for young children who will be called to act in a rapidly changing world that requires them to use their knowledge creatively. However, according to Resnick there is an exception to this trend, and that is kindergarten [47]. In a typical kindergarten classroom is it commonplace to see children learn by building with blocks and bricks, by finger painting, and more. They build knowledge through experimentation. For example, what makes a tower fall? Which colors match? Children try out ideas, test them out, learn from their mistakes, and use the knowledge they develop in new problems.

Resnick argues that to promote the creative thinking process tools must be made available to learners, especially children, which encourage them to create. In this context Resnick and his group developed well known tools including the Scratch programming environment and LEGO Mindstorms.

2.4.4 Scratch

Scratch [16] is a visual programming environment designed for use by children, primarily aged 8 to 16. It allows learners to build programming skills while working on meaningful projects such as animating objects or building games [48]. It is built on Papert's constructivism theory [49]. Through the Scratch environment learners have the opportunity to explore, experiment, and synthesize solutions to given problems. Scratch supports working with media and scripts. Sounds and media, including pictures and videos, can be imported through a built-in tool. By importing media of their own choice, which may include animations or even pictures that they take themselves, learners can create personalized stories and projects through creative processes.

The Scratch project started in 2003 and the application was launched in 2007. It was originally used in informal learning settings. It is often distributed by educational organizations such as One Laptop per Child.

Programming components are represented in Scratch as blocks or components that can be interlocked to create a program through dragging and dropping from a toolset into a programming area. Learners can execute their program and see the results of their code execution in a specific window of the application.

The shapes of Scratch components suggest how they fit together. For example, serial commands can be inserted into a loop structure in a graphical manner. Learner projects can be stored on their own computer or shared through an on-line community.

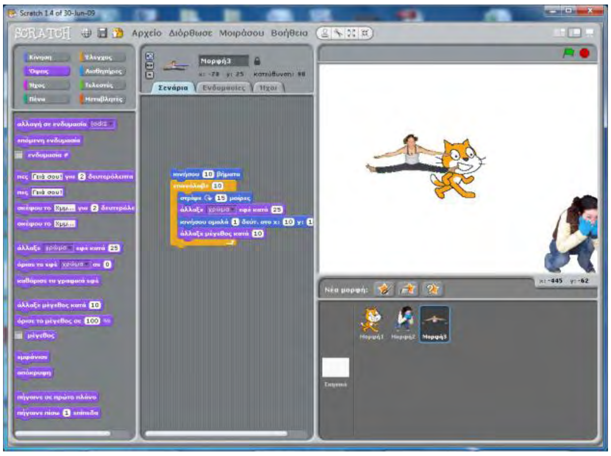


Figure 8. The Scratch programming environment.

Scratch supports basic data types and specifically Boolean, number, and string. Objects are supported as "sprites" that encapsulate state and behavior.

The Scratch community has been developed with the objective of encouraging sharing of projects. Since its inception more than 1m projects have been published on the community. Visitors can use the projects of others and even extend them; the community etiquette recommends that proper references are inserted on the origin of a project and on the original author.

Resnick and his team used Scratch at the Intel Computer Clubhouses [50], which were after school computer and technology centers targeting urban youth, and specifically youngsters 8-18. Before the introduction of Scratch, learners engaged in activities that ranged from playing Microsoft Xbox, recording music, manipulating images, and playing board games. Scratch was introduced in the Clubhouses in January 2005. Learners were encouraged to work on projects that interested them and were of their own choice. Scratch-a-thons were organized every 3-4 months in which learners worked on a project for 3-4 hours and then shared their project with others. Resnick's research team monitored learner projects over an 18 month period to see if the use of Scratch resulted into learners building programming skills. The results were very encouraging. They demonstrated that beginners used Scratch for importing pictures or drawing; however, once learners built a basic familiarity they did engage in scripting. Most learners engaged in a specific project over an extended period of time. A large number of projects included user interaction, loops, and conditional commands while less included variables, Boolean logic, and random numbers. They key question is: why did learners use Scratch more than any other programming environment? It appears that the attractiveness of Scratch is rooted in the simplification of the mechanics of programming which make it accessible for broader audiences of learners. In addition, motivation is a significant factor as Scratch allows learners to work on projects of their choice.

2.4.5 LEGO Mindstorms

Another key development of the Lifelong Kindergarten group is LEGO® Mindstorms [51]. The project was developed by Lifelong Kindergarten and The LEGO® Dacta Group. The Dacta Group aims at developing toys with an educational added value that allow children to learn actively by applying research results in psychology and cognition.

The name of LEGO® Mindstorms directly refers to the teams that collaborated on its conception and implementation: the Lifelong Kindergarten Group which draws inspiration from Papert's book Mindstorms: Children, Computers, and Powerful Ideas [18] and the LEGO® team. It is the result of 20 year collaboration between the two teams. The seeds go back to the 1960s, which Seymour Papert and the MIT Media Lab started developing educational technologies for children.

LEGO® Mindstorms is an innovative robotic construction for children. With LEGO® Mindstorms children have the opportunity to construct a robot with LEGO® bricks, attach on it a programmable "brick", and program the robot to execute specific actions. The programmable brick has the capacity to interact with the real world through sensors and motors allowing learners to develop innovative computerized constructions.

The LEGO® Mindstorms programmable "brick" is a micro-computer that can be programmed through a dedicated graphical interface on a regular PC. In the earlier days the brick was programmed using the LOGO programmed language. In later days LogoBlocks was used. Initially, the program was transferred from the PC to the "brick" through a cable. This, however, imposed significant restrictions on the movement of the robot. For this reason, in later versions of the product the transfer of the program from the PC to the "brick" was supported through wireless connections.

LEGO® Mindstorms is, in a sense, the ultimate manifestation of Papert's constructionism theory. Children literary construct their own inventions that can be programmed to interact with the environment around them.

LEGO® Mindstorms was commercialized in 1998 and was a commercial success. It is a good example of how academia and industry can collaborate towards bringing scientific ideas to the real world in an easy to understand way.

A second version of the programmable "brick" was further introduced. It was called a "cricket" and its main differentiation from the original "brick" was its smaller size.

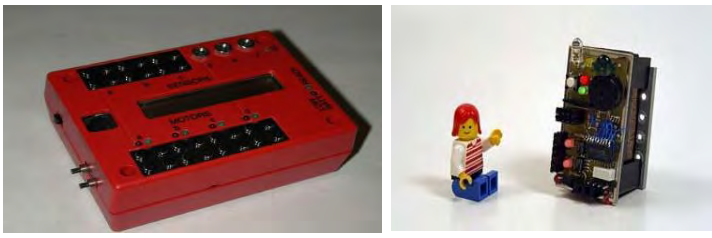


Figure 9. A programmable "brick" (left) and a "cricket" (right).

Notably the Dacta Group had made earlier efforts to introduce AI into education. In those early attempts the group faced challenges related mostly to the cumbersome programming language used and cables that were required for the control of the construction and imposed significant restrictions to its movement and the creativity of learners.

2.4.6 Digital Manipulatives

Digital manipulatives refers to children's toys with integrated computational and communications capabilities [52]. These tools were developed by Resnick and his team based on a simple idea: children at a young age explore the world using "manipulative materials". For example, toys that consist of bright colors and lengths are used to engage children in exploring arithmetic concepts and relationships. These manipulatives, however, do not help children in exploring more abstract notions; the latter are typically taught through formal educational processes which are available to children at a much later age. Digital manipulatives fill exactly this gap in education: they empower children to explore abstract concepts to which they would typically be exposed later in life by playing with digital tools. ICT can offer great advantages in this context. Through ICT popular toys can be enriched capabilities to move, to sense, and to interact making concepts related to systems easier approachable to children. Notably, without these tools children would be exposed to ideas related to systems and interaction only at pre-college age through modeling environments designed for this age group.

Resnick's team experimented by adding computational power to typical children's toys: blocks, beads, balls, and badges.

Computational blocks have already been described above; they are LEGO bricks in which computational power has been embedded.

The activity related to beads takes advantage of the popularity of beads among young learners, especially girls. Children design bead patters by linking them on a string. This process, however, generates static patterns. Adding computational power to beads allows children to create dynamic light patterns. Some beads promote the light to the next bead in the line while others absorb the light. Changing the placement of beads alter the dynamic behavior and light pattern generated as a result.

BitBalls are transparent, rubbery balls in which a Cricket, an acceleration meter, and colored LEDs have been embedded. A child can program a BitBall to turn on the LEDs based on its motion; for example the BitBall can turn red whenever it undergoes sharp acceleration.

Badges have integrated computational power and electronics that allow them to communicate with each other via infrared communication. They can also change their displays based on the signals received. One manifestation of this toy was the Thinking Tags. Each contained information on the interests and opinions of its wearer. When two people met the badges exchanged the stored information and then displayed how much the two people had in common.

2.4.7 Arduino

Arduino [53] is an open source electronic platform for building programmable prototype devices through easy-to-use hardware and software. According to the creators of the platform “it is intended for artists, designers, hobbyists, and anyone interesting in creating interactive objects or environments.

The idea behind the Arduino platform is similar to that of Lego Mindstorms®. An Arduino device includes building blocks of various forms that are used for constructing devices that interact with the environments through lights, motors, and other sensors. Similarly to Lego Mindstorms® Arduino constructs include a microcontroller chip a board that can be programmed using the Arduino programming language [54] that is based on Wiring [55], an open source programming framework for microcontrollers which supports the development of cross-platform applications for controlling a wide range of microcontroller devices.

Similarly to Scratch, Arduino has a community that encourages the sharing of projects while at the same time it provides sources for building new ones. The community is reachable through popular social networks. A wiki offers a collection of tutorials, instructions, and supporting information directly contributed by Arduino users for the benefit of others.

Arduino is used to build diverse applications, ranging from practical to artistic. As an example of what Arduino can be used for, the following image demonstrates an artistic project in which sensors sense when a plant is being touched and convert the capacitance to sound, making the plant "sing".

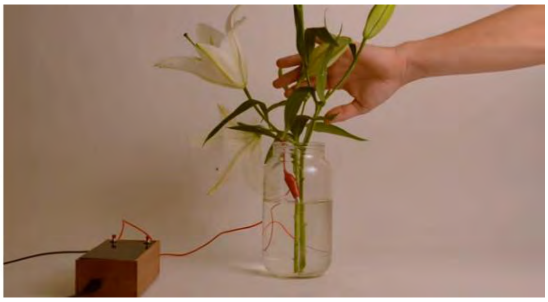


Figure 10. The "Singing Plant" Implemented with Arduino[1].

Another example, below, demonstrates an Arduino-controlled robot that consists of a 4-wheeled graffiti machine with an arm that controls spray cans to create random strokes on a wall.

Figure 11. Arduino Drawing Bot[2].

Similarly to Lego Mindstorms, Arduino offers an open platform that promotes constructivist and creative thinking by enabling users to develop innovative projects using problem-solving skills.

---

[1] Project by A. B. Kverneland, N. Padfield, T. Jorgensen, S. Lindemann, T. Lentz, DZL, V. Carpenter), on-line at: http://www.instructables.com/id/Singing-plant-Make-your-plant-sing-with-Arduino-/

[2] Project by S. Kanno, T. Yamaguchi at the Exhibition "UTOPIA no OSHIRASE that took place at AKIBATABAB, Tokyo in 2011, on-line at: http://www.creativeapplications.net/arduino-2/senseless-drawing-bot-arduino/

2.4.8 Alice

Alice is programming software that teaches students programming. Activities take place in a 3D environment [56] [57] [58] [59]. It has been developed by Carnegie Mellon University. According to its authors, the Alice project [19] provides tools and supporting material for “teaching and learning computational thinking, problem solving, and computer programming across a spectrum of ages and grade levels”. It allows learners to create in an easy manner animations for story-telling, interactive games, videos, and more and to share the outcomes on the web.

To support the programming process Alice introduces an interactive programming interface through which students “drag and drop graphic tiles” to synthesize a program. The programming constructs supported by Alice are typical ones available in object-oriented programming languages such as Java and C++. Similarly to Scratch, Alice allows students to immediately see the results of the execution of their animated program allowing them to develop an understanding of the relationship between blocks of commands and their effect on the behavior of the objects in their animation. Through this process Alice allows learners to develop knowledge typically taught in introductory programming courses.

Figure 12. The Alice Programming Environment by Carnegie Mellon University.

Evaluation results demonstrated that ‘students developed a justifiable sense of self-confidence in their programming and an intuitive feel for objects, methods, and programming constructs’ [58].

2.4.9 Kodu

Kodu [60] [61] is a programming environment developed by Microsoft®. It is a visual programming language developed by Microsoft® Research with the purpose of allowing learners to build games. It is distributed free of cost. The programming environment runs on Xbox. It allows learners to build basic understanding of programming processes. The Kodu interface has been translated in 10 languages. Similarly to Scratch, Kodu has its own community through which members can post and share projects. The programming environment is fun and attractive to learners. It promotes the development of problem solving skills, digital skills, as well as collaboration through its community.

Kodu offers a wide range of "worlds" that a learner can use to build projects. In addition, it offers a wide range of objects that the learner can use in her projects or manipulate through programming to develop new entities or to alter the object's behavior. Kodu promotes object-oriented programming.

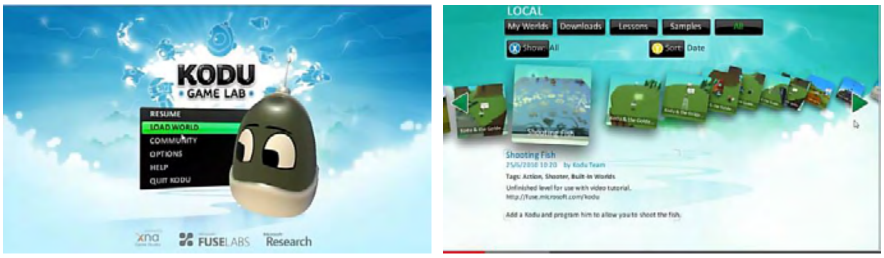


Figure 13. The Kodu programming environment, source "Creating Games in MS Kodu"

2.5 Serious games

This section introduces serious games and provides a discussion of potential learning benefits. It further presents serious games designed for deployment in diverse contexts.

2.5.1 Definitions of serious games and common uses

Michael and Chen (2006) define "serious games" as digital games that have been developed for a purpose other than entertainment [62]. Others define serious games as simulations of real world events or processes designed for the purpose of solving a problem. Serious games are seen as alternative educational applications that, when designed properly, constitute affordable, accessible, and familiar training environments for a wide range of educational and training scenarios and situations (Stone 2005) [63]. While serious games can be viewed as entertaining the main objective of their design is to educate or build skills. Increasingly they are used for promoting behavioral changes, motivation, and skill building in broad sectors, including:

- Medicine and health-related jobs
- Business education
- Professional lifelong learning
- The military
- Crisis management
- Scientific exploration
- And more

Serious games offers a large range of benefits in the context of education and training design that include, but may not be necessarily limited to, the following:

- Games introduce puzzles and everyone likes to solve a puzzle! Serious games can be used as motivational tools for promoting long-term engagement with the learning process
- Games have clear and interesting objectives; this characteristic of games in general, when exploited correctly in educational game design, can help link activities to specific learning objectives
- Games introduce feedback in imaginative ways. Games provide feedback when needed, in real-time immediately after a user executes an action enabling users to make a connection between cause and effect of their actions and to understand why a specific choice may be right or wrong
- Games integrate elements of fantasy and surprise that are attractive to users and may positively contribute towards engagement with learning
- According to the Federation of American Scientists games can contribute to the development of higher order thinking skills including strategic thinking, interpretative analysis, problem solving, decision making, and adaptation to rapid change [64]. Completing tasks set by the game challenges users to master skills that are in demand by employers. These are skills that are expected to be highly in demand by employers over the coming years according to the European Commission Digital Agenda [4]. Evidence that video games may contribute to the development of useful skills among young learners was produced in early research in the area by Subrahmanyam and Greenfield (1994) [65]; de Freitas (2006) [66]further suggested that serious games might be an attractive new method of learning [67]

- On the other hand, according to the Federation of America Scientists digital games can further contribute to the development of "hands-on" skill sets and teach practical and technical skills that can range from fixing a car to performing a surgery [64]
- Similarly to simulations games may allow learners to build skills in a virtual environment in cases when physical facilities may not be used. This for example may be when:
  - Facilities are not available
  - The use of facilities is very costly; for example, training future workers or retraining workers in real-life factory facilities requires down-time that may be significantly expensive. Serious games can provide a virtual environment in which individuals can practice their skills at little cost before practicing in physical facilities
  - Danger is involved; for example, training pilots begins with flight simulators which are virtual environments in which professionals can practice safely maneuvers before executing them in a real-life plane; similarly, building skills on executing delicate medical procedures may take place in a simulator allowing trainees to build skills and confidence before applying their skills in real-life conditions that involve actual patients

2.5.2 Serious games vs. digital games in learning contexts

The question may arise as to what actually constitutes a serious game. Some games are developed with the objective of being used solely for educational or skill building purposes. These are digital applications to which the term "serious games" naturally applies based also on well-accepted definitions outlined in the previous section. Consider, however, a game that has been developed for entertainment purposes, for example a Tom Clancy game. The purpose of the game for the user could be summarized as follows: the user finds herself in a futuristic urban environment in which the user is called to kill everyone that she encounters with the exception of team members. This game could not be defined as an educational game. In fact, serious objections could be raised related to the exposure of users to violence and what the consequences of that might be. However, the user does build specific skills in this game, which include collaboration, leadership, and problem solving skills based on the fact that the user's avatar collaborates with non-playing characters to achieve her goals. This extreme and controversial example shows how digital games, which are not designed as serious games, can contribute to skill building.

Similarly, consider the game of Angry Birds ®. The purpose of the game is to help the birds retrieve eggs that have been stolen by pigs using imaginative solutions that are based on physics. The widely successful game has been designed for entertainment purposes. However, it could be used by a teacher for explaining physics laws in the context of broader learning activities.

2.5.3 Serious games in the classroom

A question may arise as to why to use serious games in formal educational environment such as the classroom when the school system, taking into account existing challenges, meets educational goals and has been proven to be effective over many decades.

In 2001 Prensky characterized the young generation as "digital natives" [68]. This term aims at highlighting the important issue of the digital divide, i.e. the fact that some individuals are comfortable with emerging ICT and others are not, with age being a significant distinguishing factor: younger individuals born in the nineties or close to the millennium have been exposed early in life to ICT advances including both devices and services. The term "net generation" is used to describe the generation that follows the "millennials". As Oblinger and Oblinger [69] argue, the net generation involves individuals that have grown up with ICT and are used to be connected to others through on-line services and communities. This results to a new set of aptitudes, attitudes, expectations, and learning styles that reflect the environment in which they were raised and which cannot be ignored when designing learning activities for addressing the needs of this group.

However, a gap may be observed between the fast adoption of ICT and networks by the young generation and perceptions of parents and even teachers. It is not uncommon for a parent to urge a child to "stop playing and go study", showing negative attitudes towards the integration of games in education. It will be difficult for a teacher that expresses herself in a similar manner to introduce serious games in the classroom or to motivate learners to use serious games as learning tools.

In a study that was carried out at the University of Texas Metcalf in 1997 observed that people “remember 10% of what they read; 20% of what they hear; 30% of what they see; 50% of what they see and hear; 70% of what they say; and 90% of what they do and say” [70].

De Freitas (2006) [66] argues that the deployment of serious games in the classroom is likely to increase. The important question is how games can be effectively integrated into learning in a manner that ensures knowledge increase and scaffolding. The following graph by Garris (2002) [71] demonstrates an approach in which games are integrated into wider learning processes that do not only include gameplay and engagement but also debriefing processes, behavior analysis, and feedback all in relation with the desired learning outcomes and game content and characteristics. Through this game cycle the risk of random choices during gameplay is minimized while the correlation of engagement to learning outcomes is maximized.

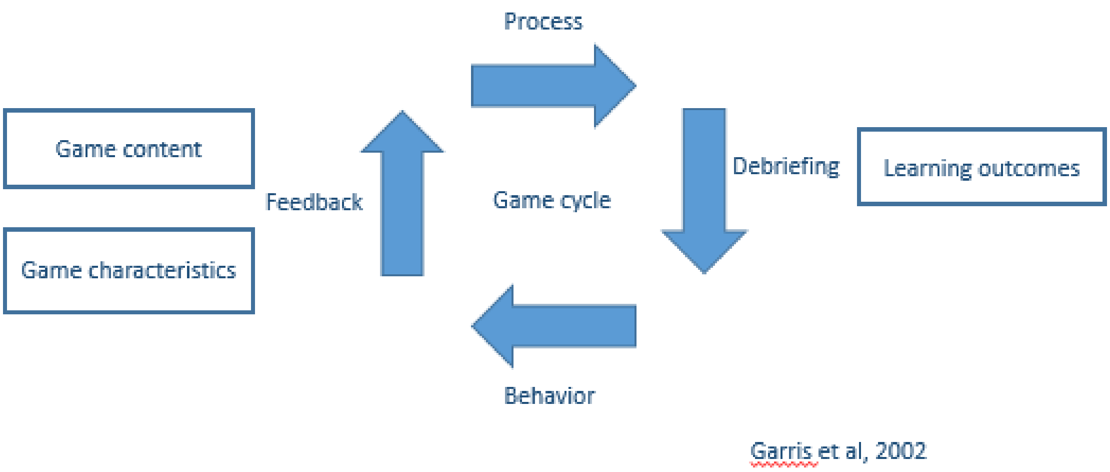


Figure 14. Game cycles, Garris et al. 2002.

Another question is: should we first start with education or with fun? Zickerman and Cunningham argue [72] that trying to introduce fun into education may not have as high an impact as introducing educational aspects into fun for example as backdrop to a game scenario. Rice (2007) argues that virtual games used for educational purposes can be categorized as either simpler, edutainment games or games that facilitate higher order thinking [73]. Citing Kirriemuir and McFarlane (2003) [74] [75] Rice further observes that edutainment games are more likely to be used in classrooms because they are simple to use and have low technical requirements that allows them to be deployed even on older computers and school labs. Rice provides as an example of ‘lower learning’ drill games for mathematics such as Math Blaster®, one of the very popular games for ages 6-7. These games do offer learning benefits by motivating students through gaming mechanics, such as opening an arcade game upon successful completion of an exercise, to practice extensively. However, a lot more can be achieved through serious games. Bloom’s taxonomy (1956) from lower to higher order thinking levels includes: ‘knowledge, comprehension, application, analysis, synthesis, and evaluation’ [76] [77]. Engagement in related learning activities, which are defined for any learning process, is also desirable for games that promote higher order thinking. Other aspects that promote higher order thinking include interaction, combination of elements for synthesizing knowledge, an environment that replicates the real world, replayability with varying results, puzzles, and more [73].

Serious games can be exploited as a starting point for instigating educational processes or as tools that reinforce knowledge introduced through more traditional processes, such as class instruction, through active learning, feedback generation, and long-term engagement with learning.

While currently serious games are not formally introduced in most school curricula the perceived benefits of serious games have led to initiatives and experimental schools that promote flexible curricula exploiting serious games in pedagogical contexts. An example is Quest to Learn [78] which uses games for promoting problem solving skills and innovative thinking for the next generation. Games are further used for building systemic reasoning, critical thinking, judgement, and credibility as well as learning through designing.

2.5.4 Examples of serious games targeting diverse user groups

Serious games are used for life long skill purposes in diverse sectors. Serious games are used broadly to increase knowledge, change behavior, and increase experience. Serious games are used in diverse sectors that range from primary education to higher education, professional training, and lifelong skill building. According to Connolly et. al. (2012) serious games can further impact motivation, engagement, perceptual and cognitive outcomes [79].

Serious games are further deployed to address complex social issues through attitude changes; for example, for fighting xenophobia, raising awareness on poverty, raising awareness on the importance of leading a healthy lifestyle, and more.

Serious games are particularly used in the sectors of business education and medical training as well as in the military. They offer advantages in terms of exposing users safely to complex processes building experience in a simulated environment before applying skills in the real world.

The following sections present serious games that have been developed with the objective of addressing targeted needs of specific end-user groups.

2.4.4.1 EnvKids: a serious game for primary environmental education

The EnvKids project [80], which ran from 2009 to 2011 with support from the Comenius action of the Life Long Learning Programme of the European Commission [81], focused on building environmental skills among primary education learners through educational games. The project was coordinated by the Center for Research and Technology Thessaly with the participation of several partners throughout Europe, including the University of Thessaly. The project focused on building environmental awareness skills and environmental responsibility for the next generation. Two serious games were developed under the umbrella title "my home, my town, my planet"; the games targeted primary and lower secondary education learners. They differed from other related activities in learning design: the applications were developed with the objective of being used in the classroom as complementary learning tools in the context of wider blended learning activities (Tsalapatas et al 2010) [82] [83] [84].

The first application, titled "my home", aimed at building awareness among young learners on environmentally friendly behavior at home that leads to the reduction of environmental pollution through house improvements and every day activities that reduce emissions from energy consumption at home. Examples of house design improvements include enhanced insulation that helps keep the house warm in the winter and cool in the summer, use of renewable energy sources for covering parts of a home's every day energy needs such as solar panels for heating water, designing a house with orientation that helps maintain internal temperatures at desirable levels, for example south-north orientation, recycling, and more. Examples of environmentally-friendly behavior that a child is encouraged to develop including turning off idle electric devices, setting room temperature to appropriate levels based on function – for example the temperature of a bedroom can be a couple of degrees lower than the temperature of a living room, avoiding the placement of heat-producing devices, such as an oven, next to devices that preserve low temperatures, such as a refrigerator, setting the temperature of the water heater to desirable levels that ensure comfort, ensure germ control, and do not waste energy, using electric devices at off-peak hours, and more. This application applies explorative learning in a closed environment, meaning that the user selects from visually depicted multiple choices. Feedback is presented in the form of a wheel that becomes greener as house design and player behavior becomes more environmentally sound.

The second application, titled "my town", is an open-ended game that encourages learners to design a town, then try to cover the town's energy needs while at the same time ensuring that pollution levels are low. This game does not have a correct or wrong conclusion. Rather, it aims at facilitating conversation among class participants on what is correct or wrong. Learners first build a town grid; as feedback they see the energy needs of the town, which increase with newly added homes, business buildings, or malls. They are asked to introduce energy production facilities that cover the energy needs of the town inhabitants. Learners may choose from a range of choices, from traditional coal-burning factories to emerging renewable energy-based solutions that involve windmill parks or photovoltaic panels. Learners receive feedback on their efforts in the form of a meter that shows the extent to which energy needs are covered and a quality of life indicator in the form of a person whose mood varies depending on town design.

Figure 15. The EnvKids serious games for environmental skill building among young learners.

A third application, titled “my planet”, is not a serious game but rather a digital library with a Google Maps® interface of environmental information for a group of countries. The information includes pollution levels, endangered species, forest cover, consumption of natural resources, and more. The information is retrieved from international data banks and is presented in a child-friendly manner.

2.4.4.2 siLang: a serious game for work-related language skill building

The siLang project [85], which is funded with the support of the Life Long Learning Programme of the European Commission, deploys serious games for introducing situated learning towards building language and cultural skills for the world of work. The project is coordinated by the University of Thessaly with the participation of several partners throughout Europe. The serious game views languages as a work tool. The game builds communication skills in vehicular languages, or lingua franca, i.e. a commonly understood language that individuals that do not share a mother tongue resort to for communicating for business or other purposes.

siLang departs from typical language learning software design by exposing users to the way a vehicular language is used by both native and non-native speakers with a focus on the latter.

The software recognizes the fact that when a language is used as a work tool what is most important is effective communication rather than speaking the language with absolutely no mistakes. In addition, the software takes into account so called “transfer effects”, i.e. influences from an individual’s mother tongue when communicating in a second language, which can be expressed in the form of syntax application, choice of words, or choice of expressions.

In today’s multi-cultural and international work environment individuals that use vehicular languages for work are still primarily interested on achieving their business objectives. Professionals with diverse backgrounds that communicate in vehicular languages will rarely correct each other’s second language mistakes if the main message of a communication comes effectively across.

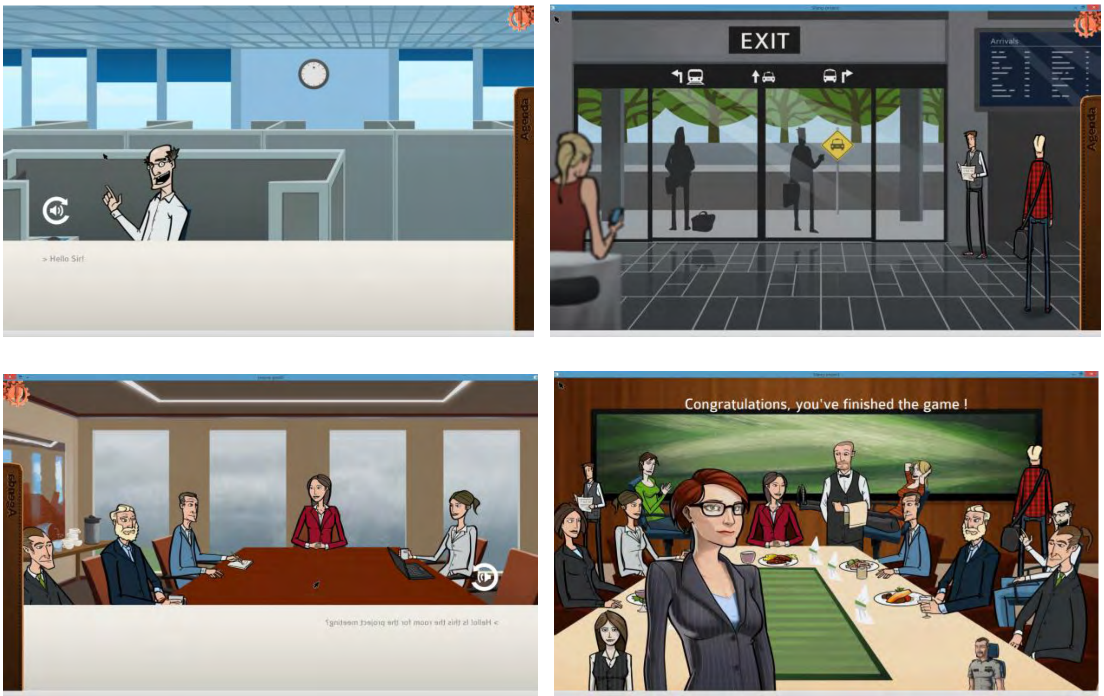


Figure 16. The siLang game for building language and cultural communication skills in a lingua franca for work use.

The siLang serious game exposes users to how a vehicular language may be used by individuals with diverse backgrounds [86] [87] [88] [89]. The application is designed for preparing an individual to effectively communicate in a lingua franca in professional contexts. The scenario of the application follows typical activities performed in the world of work such as taking part in an interview, negotiating hiring salary, preparing for business travel, participating in an international professional meeting, participating in a social professional dinner, and more. The game focuses mostly on comprehension, with an emphasis on listening comprehension. The user is called to demonstrate sound understanding through mini-games that are executed by exploiting information offered by non-playing characters. The non-playing characters of the game have rich backgrounds; the characters are assigned authentic voices by individuals with backgrounds from diverse European countries, including Greece, Estonia, Norway, Portugal, and Italy.

The game offers a first person view popular among users of commercial games. The user communicates with non-playing characters by selecting from a list of multiple choices in a manner similar to that deployed widely in games designed for entertainment.

Players get feedback on their communication efforts in multiple forms. For example, a non-playing character may react to comprehension errors by offering the correct information. On the other hand, a post-it note may provide the user with information on inappropriate practices, for example impolite behavior.

The choices a user makes influences, to a certain degree, the evolution of the game scenario enhancing the replayability of the game and offering the user with sense of control.

2.4.4.3 TALETE: a serious game for secondary math education

The TALETE project [90], which was funded with the support of the Comenius Action of the Life Long Learning Programme focused on the development of math, and more specifically geometry, skills among 15 year old learners through the deployment of serious games. The project was coordinated by Universita degli Studi Guglielmo Marconi with the participation of several partners throughout Europe, including the University of Thessaly. TALETE, which is the Italian name of the Greek philosopher and mathematician Thales, focused on this target group for reasons very similar to the ones described in this thesis, which include the fact that learners in many countries underperform in STEM education, the correlation that has been identified between performance in STEM at the final year of obligatory education in many countries, which is year 9 of obligatory education, and performance of learners in later educational endeavors such as tertiary education, and the fact that STEM skills are highly in demand by the innovation sector which is seen as a sector that has the potential to drive economic growth in the following years.

The TALETE application introduces learners to challenges that are drawn from actual school curricula in several European countries. This choice was made specifically for ensuring that the application has direct links to formal STEM secondary education. Learners are rewarded through items in an inventory that are necessary for building a spaceship and travelling to space.

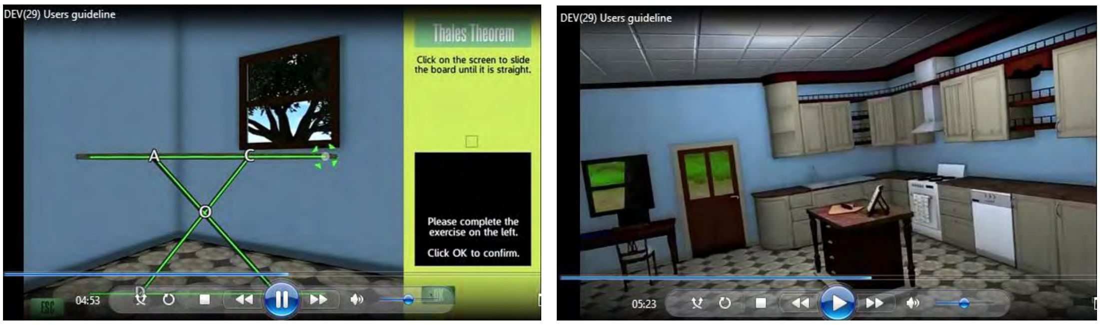


Figure 17. The TALETE virtual world for building geometry skills.

Examples of learning challenges include: identifying shapes and measuring their space in a roman mosaic, measuring the distance of a boat from land using the Thales theorem, calculating the space of triangular pools, calculating distances among houses in a village, and more. The project has been completed and the application is available on request.

2.4.4.4 The Magic Potion: a game for skill building among young learners with light learning disabilities

The Magic Potion [91] is an adventure game that targets children with light mental disabilities. It was developed by the Laboratory for New Technology in Communication, Education, and Media of the Department of Communication and Media of the University of Athens (Pr. Mihalis Meimaris and a group of 15 researchers in diverse fields).

Figure 18. The Magic Filter game for building skills among learners with light learning disabilities.

The Magic Potion is an autonomous game developed in Flash. The game involves several characters (it is not a single character game), all of which help each other to achieve the game objective of mixing a magic potion by collecting colors that are hidden into the game "world". The colors are "earned" as a result of successfully completing specific activities that help the learner build basic life and communication skills as well as basic arithmetic, writing, and reading skills.

2.4.4.5 Serious games for geography

‘Where in the world in Carmen Santiago’ is a well-known game that aims at building geography and reference skills. The game was first developed in 1985 but several newer editions have been released since then including a version for Facebook® released in 2011. The player is asked to travel the world for locating and arresting villains through clues collected through the game. The game has been designed for entertainment purposes but the activities that the user is asked to execute help build knowledge combining teaching and fun.

2.4.4.6 Serious games for business education and corporate training

Serious games for business education are produced commercially for wide subjects by educational publishers. Such games are sometimes developed by large corporate players for internal training purposes. Examples of games developed for business training are described below.

The INNOV8 [92] serious game was developed by IBM and aims at building Business Process Management (BPM) skills through simulations. The game targets both business players and IT personnel and aims to increase awareness on how effective BPM can positively affect an entire business ecosystem. The game exposes users to specific business process scenarios and challenges them to introduce improvements for increasing effectiveness. Examples of scenarios introduced by the game include: Smarter Traffic, in which users are asked to review traffic patterns and re-route traffic based on metrics; Smarter Customer Service, in which players are asked to design an effective call center for efficiently responding to customer demands; and Smarter Supply Chains, in which users are asked to balance supply and demand and reduce environmental impact in a traditional supply chain model. Upon completing a task, users can compare scores published in a scoreboard.

McGraw Hill Practice Series Games [93] is a line of 3D multiplayer learning games published by McGraw Hill Education. They provide hands-on experience developed through experiential learning models. The games are developed for targeting specific learning needs and objectives. Examples of some of the games commercially available through this series include: Practice Marketing [94], which is a multiplayer business strategy game that uses simulations to help users build marketing skills through fun and competitive learning tasks. It challenges users to build their knowledge on practically applying basic marketing principles that they learn in class such as the “4 Ps” framework, i.e. Produce, Price, Placement, and Promotion.

The Practice Operations game in the same series encourages users to build operations management skills while at the same time developing analytical capacity and decision making skills. Role playing learning mechanisms are applied. The user assumes the role of operations manager in a company and is called to manage contracts, human resources, ordering, production, and shipping. Users build knowledge in supply chain management, labor management, and quality control.

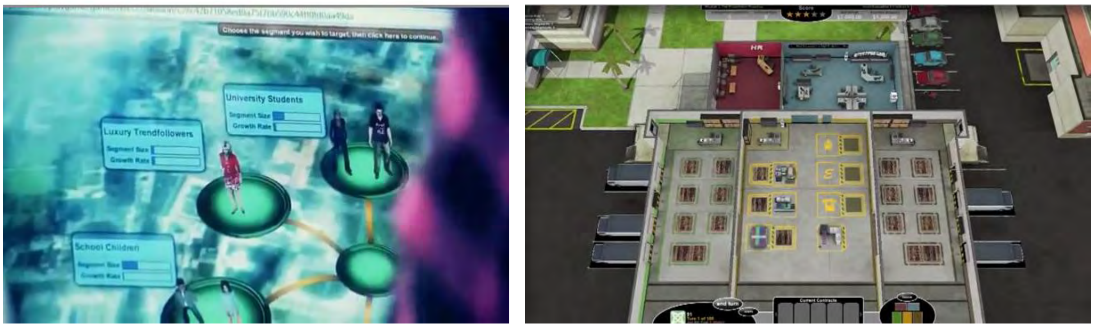


Figure 19. Screen Shots from McGraw Practice Series Games: Practice Management (left); Practice Operations (right).

The Learn to Lead (L2L) game [95] is developed with the support the European Agency for Education, Culture, and Audiovisual in the context of a research project with the same title. The game targets SME staff, small government office staff, NGO staff, and more. It aims to build users’ leadership and management skills. In the game users manage a team of employees that work in diverse environments that range from banking to government services. The user competes against other players and strives to maximize the outcomes of her team based on specific business objectives.

2.4.4.7 Serious games for social inclusion

Serious games are exploited not only for building knowledge but also for positively affecting attitudes and perceptions and affecting social change. According to the

Potential of Digital Games for Empowerment and Social Inclusion of Groups at Risk of Social and Economic Exclusion: Evidence and Opportunity for Policy JRC Report by Stewart et al (2013) [21] and the Europe 2020 Targets [96] an estimated 110m individuals, 23% of EUs population, are at risk of social exclusion in Europe today. According to Bianchi et al. (2006) [97] social exclusion is "very expensive, economically counterproductive and lays a heavy social and political burden on society". Social exclusion is a complex issue that is affected by a combination of factors that include lack of basic competences, discrimination, unemployment, limited access to basic services such as child care and housing, and more. Stewart et al (2013) argue that the high percentage of individuals that are at risk of social exclusion "presents society, entrepreneurs, and policy makers with a challenge that calls for innovation of all types to tackle" the combinations of factors that lead to social exclusion [98].

Groups that are at risk of social exclusion include school dropouts and individuals that are not in employment and not in education (NEETs), older individuals with chronic disease, migrants, older women trying to re-enter the workforce after having raised children, carers trying to balance work and care, and more. According to Makinen (2006) [99] empowerment of individuals for social inclusion means "enabling people to do what is important to them, to grow as competent subjects who have control over their lives and surroundings. This refers to building attitudes and motivation, self-efficacy and self-confidence, social support, social context, core skills, wellness and personal well-being, access to services and infrastructure [100].

Digital games can be relevant to many of the above areas. Processes for building skills and positively affecting attitudes can be enriched through game-based learning approaches, simulations, pervasive games, and gamification.

Examples of serious games that have been developed with the objective of promoting empowerment are discussed below.

InLiving [101] aims at addressing homelessness and housing quality. It is a free mobile phone game that aims to raise awareness of dangers of independent living among young homeless individuals. It supports the re-engagement of NEETs and has succeeded in increasing tenancies by 10%.

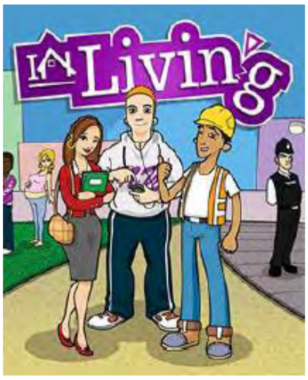


Figure 20. InLiving game, JRC report on the use of digital games for empowerment and social inclusion.

Poverty is Not a Game (PING) [102] targets teachers and provides classroom and home support for raising awareness among young individuals on poverty. The game has 40K on-line players and 5K downloads.

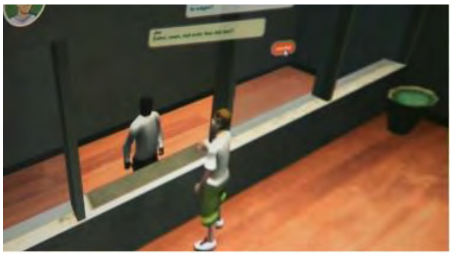


Figure 21. Poverty is not a game.

At-Risk [103] is a game that targets university staff and aims to empower them to identify mental distress among students with the objective of preventing suicide.

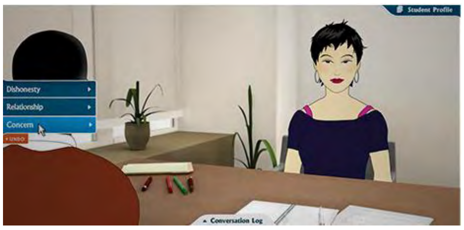


Figure 22. At-Risk game for raising awareness on preventing suicide on-campus.

2.4.4.8 Serious games for medical training

Serious games deployment for training of medical personnel, including nurses and doctors, are widespread in comparison to their use in other lifelong learning sectors. This is not surprising based on the traditional dependence of the sector on practicing medical procedures for training purposes in simulated settings and environments before executing on patients in real-life situations. As Graaflang et. al (2012) argue, “priority safety concerns call for the need to train medical personnel in simulated settings to reduce cost and patient morbidity”. Michael et al (2006), cited in Graflang et. al (2006) further argue that “[serious games] present an ideal playground to engage players in simulated complex decision-making processes like those required in medical training” [62] [104]. Examples of serious games built for training purposes in the healthcare sector are described below.

The eMedOffice game, which is currently in use by the RWTH Aachen University Medical School [105], aims at preparing medical students organizationally and conceptually for organizing a medical practice. The game uses problem-based learning and competitive aspects to promote engagement and motivation among learners. The game was developed for integration into medical school curricula courses. The game scenario challenges learners to meet the needs of patients based on the available staff resources and rooms. It helps learners build analytical skills as well as planning and deductive skills using patient feedback. The game uses an adapted version of the input-process-outcome game model introduced by Garris et. al (2002) [71]. The game targets medical school students.

The CliniSpace® application [106] and its predecessor Virtual ED developed by Stanford University were introduced for building skills in advanced trauma support. They are immersive applications that expose users to realistic scenarios and problems which they can address either independently or in groups. In addition to building skills for trauma support users build decision making and communication capacity. The CliniSpace® application is commercial. The game targets physicians and nurses.

A game that focuses on building surgical skills was introduced by Cowan et. al (2012) [107]. The game targets medical students, fellows, and residents in a series of steps involved in performing coronary artery bypass grafting. It is a first-person-shooter gaming environment that offers learners a better understanding of the medical procedure than traditional learning practices. The game allows users to adjust simulation parameters related to fidelity.

2.6 Learning methodologies related to serious games

Following is a discussion of emerging learning methodologies applicable on the development of knowledge in diverse subject areas as well as analytical and critical thinking capacity.

2.6.1 Experiential learning

Experiential learning is defined as a process of ‘learning through experience’ [108]. Work on experiential learning started in the 1970’s by David Kolb who introduced his four stage model of ‘experiential learning cycle’, demonstrated in the following figure. Kolb described ‘learning as a process whereby knowledge is created through the transformation of experience’ [109]. According to Kolb, one may begin the learning cycle at any of the four stages, but must follow the rest through in sequence. Kolb suggests that the learning process often starts with a person carrying out a particular task and witnessing the effect of the action in a particular situation.

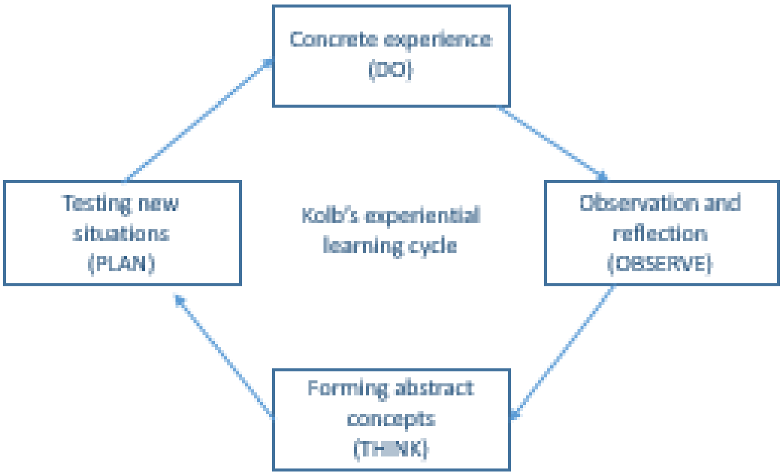


Figure 23. Kolb’s experiential learning cycle.

Kolb is particularly interested in how concrete experiences affect learning styles. He built on work by previous researchers making explicit references to the work of Piaget as well as Dewey and Lewin. Dewey, one of the most influential researchers on education in the 20th century focused on interaction, reflection, and experience and had an interest in community and democracy [110]. Dewey believed that learning begins with the curiosity of the learner. Lewin focused on experiential learning, group dynamics, and action research [111].

Other definitions of experiential learning include that of Peter Jarvis (1995) [112] who states that experiential learning 'is actually about learning from primary experience, that is, learning through sense experiences'. Jarvis expanded the work of Kolb by experimenting with Kolb's learning cycle in diverse cultural groups of adults [113]. Participants were asked to describe a particular learning incident in their lives and to either adapt Kolb's model or create a new learning model. Jarvis combined the results of approximately 300 participants in a new model. Jarvis (1987) [114] suggested that 'all learning begins with experience' and that 'real learning begins when a response is called for in relation to an experience'. Jarvis questions whether real learning has taken place if a person remains unchanged from a particular learning situation. Jarvis introduced reflection into his learning model, which was not present in Kolb's model. The Jarvis experiential learning model is presented in the following figure.

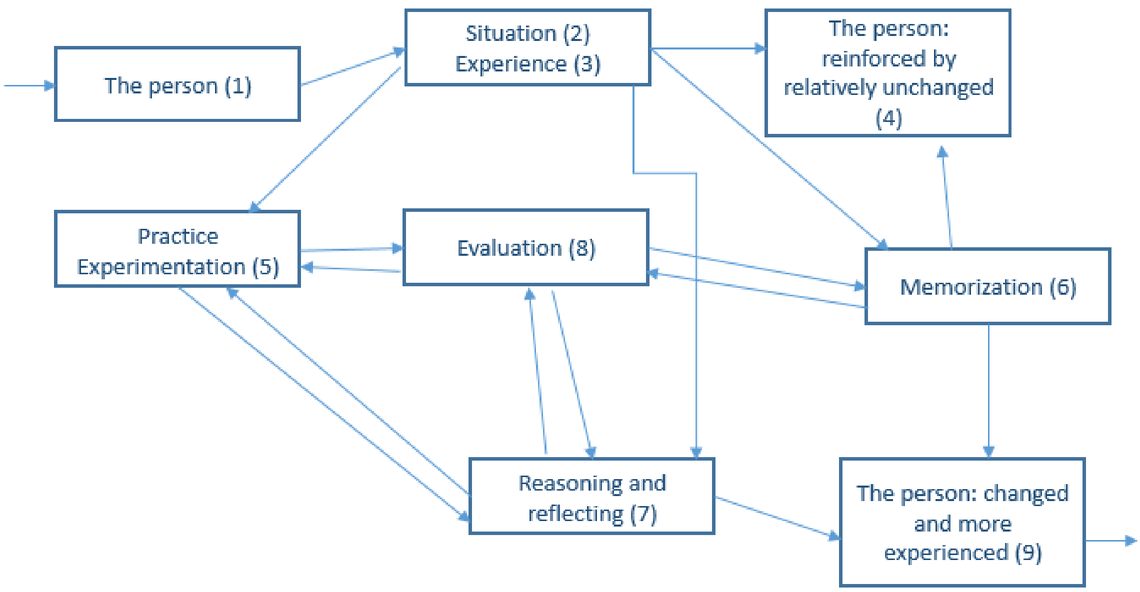


Figure 24. Jarvis's experiential learning model (1994).

On the other hand, David Boud introduced the concept of 'immersive experience' [115] [116], which describe situations in which a learner is fully engaged in the learning process. Boud advocates that through immersion learning takes place 'effectively and somewhat naturally' and argues that immersion is a 'condition that is needed for any learning to occur'. Baud provides the example of language learning through immersion in a language culture; in this case immersion is a highly effective tool for communication with speakers in another language. He further argues that the same principle holds when learning other subjects such as mathematics.

2.6.2 Active learning

Active learning is a process in which the responsibility of learning is placed on learners [117]. Michael Prince (2004) defines active learning as an ‘instructional method that engages students in the learning process’ [118]. Charles Bonwell and Jim Eison (1991) [119] advocate that ‘active learning requires students to do meaningful learning activities and think about what they are doing’. Richard Felder and Rebecca Brent (2009) [120] define active learning as ‘anything course-related that all students in a class session are called upon to do other than simply watching, listening, and taking notes’. Zull (2011) [121] defines active learning as ‘lifelong learning built on experience’, emphasizing ‘doing’ like other researchers. Linking active learning to experiential learning, Susan Ambrose et al. (2010) [122] define learning as ‘a process to change, which occurs as a result of experience and increased the potential for improved performance and future learning’.

Active learning is often contrasted to traditional learning in which students passively receive information conveyed by the instructor. Active learning may refer to a range of activities including assignments and projects outside the class, going on the field, interacting with peers, executing lab work, and more. The term, however, is mostly used to describe activities that take place in the classroom and/or promote student engagement. In its simplest form active learning may be manifested through pauses in traditional lectures during which students are asked to perform specific tasks. Other approaches of active learning may include working in groups to respond to non-trivial questions, replying to ‘concept tests’, such as multiple choice questions with distractors [120], and working in pairs and thinking out loud. Other alternatives include two mini-lectures that are separated by a small group-study session or a guided lecture in which students listen to a presentation, take a short break for writing down what they remember, and subsequently working in study groups for elaborating on the material [119]. The activities that a teacher can deploy to promote student engagement are limited only by the teacher’s imagination.

Whitney Berry (2008) [123] argues that while active learning approaches may differ they revolve around four elements: critical thinking, individual responsibility in learning, involvement in open-ended activities, and organization of learning activities by the professor.

Arthur Chickering and Zelda Gamson (1987) [124] suggest that in order to be actively involved students must be engaged in higher order thinking processes such as analysis, synthesis, and evaluation. They further must be involved in processes that depart from listening and including writing, reading, discussing, and solving problems.

The advantages of active learning are many. Active learning can help reinforce concepts, provide immediate feedback to learners in the classroom, increase motivation, create a sense of community in the classroom through collaboration, and allow learners to build knowledge in small steps starting from what they already know. The benefits of active learning are further underscored in recent research by Jamie Jensen, Tyler Kummer, and Patricia Godoy (2015) [125] who found that benefits of popular emerging approaches such as the flipped classroom may actually be rooted in active learning methods. In the context of this research the flipped classroom approach was applied by exposing learners first to educational content and then to the lectures that present it. This result was reached by observing similar groups of students who were exposed to active learning with or without a flipped classroom methodology and who achieved comparable scores at the end of the learning period.

2.6.3 Problem-based learning

Problem-based learning (PBL) was first instructed in the medical school program at McMaster University in Hamilton, Ontario, Canada in the 1960s by Howard Barrows (1996) [126]. According to Boud and Feletti (1997) [116] ‘PBL as it is generally known today evolved from innovative health sciences curricula introduced in North America over 30 years ago. Medical education, with its intensive pattern of basic science lectures followed by an equally exhaustive clinical research program, was rapidly becoming an ineffective and inhumane way to prepare students, given the explosion of medical information … Medical faculty at McMaster University in Canada introduced the tutorial process, not only as a specific instructional method (Barrows and Tamblyn, 1980) but also as central to their philosophy for structuring an entire curriculum promoting student-centered, multidisciplinary education, and lifelong learning in professional practice' [127] [116]. Since then, the application of PBL has spread to many other study areas. Through this approach students built theoretical and practical skills through simulated patients. Borrows describes PBL as a process that is student-centered that occurs in small groups. Teachers act as facilitators of the learning process. Problems are used to organize and stimulate learning.

According to Prince (2004) [118] problem-based learning (PBL) is an 'instructional method where relevant problems are introduced at the beginning of the instruction cycle and used to provide context and motivation for the learning that follows'. Prince describes PBL as one of the elements of active learning.

Other definitions of PBL include that of Robin Fogarty (1997) who defines PBL as 'a curriculum model designed around real life problems that are ill structured, open ended, or ambiguous' [128] and further suggests that 'PBL engages students in intriguing, real, and relevant intellectual inquiry and allows them to learn from these life situations'. Wendy Hillman (2003) argues that PBL is particularly relevant in professional education because it aligns theory to practice [129]. She argues that in PBL 'teachers provide information to create opportunities for students to learn'. Hillman further advocates that PBL inverts the normal educational process followed in formal education during which students build the knowledge required for solving a problem before being exposed to it; rather, in PBL students build the desired knowledge during the problem solving process.

While there is a general consensus about the high level meaning of the term, the implementation of PBL may differ significantly. Donald Woods, Richard Felder, Armando Rugaria, and James Stice discuss many different implementations of PBL including the application of research-based strategies across courses, in-depth problem solving, and helping students make connections between the problem, the required knowledge, and the solution [130]; the same authors list additional activities as elements of PBL processes including the identification of skills to be developed, the integration of related activities into curricula, the explicit description of the behavior associated with successful acquisition of the desired skills, extensive practice towards the development of the skills, monitoring and self-monitoring, reflection, and evaluation of not only the final outcome but also of the problem-solving process.

Prince argues that PBL positively affects attitudes and engagement of learners in the learning processes and promotes higher knowledge retention. In addition, it contributes to the development of wider lifelong learning skills, including the ability to collaborate, critical thinking, self-directed learning, and the ability to transfer knowledge and re-use it in real-life contexts. Similar remarks are made by Hillman. On the other hand, Stan Seltzer et al. (1996) [131] argue that through PBL 'students develop a deeper awareness and ownership of important concepts in the course by working on activities, a basic tenet of the constructive approach to learning'. Wini Gijselaers (1996) [132] describes other benefits of PBL as encouraging students to be aware by being conscious of 'what information they already know, what information they need to know to solve the problem, and what strategies they need to use to solve the problem' [133]. This principle of 'knowing about knowing' is described by Gijselaers as 'metacognition'. The importance of metacognition, or the need for students to think about what they are doing, is also emphasized by Zull [121]. Gijselaers connects PBL to emerging cognitive theories by saying that PBL 'derives from the theory that learning is a process in which the learner actively constructs knowledge' [132] and that problems act as a stimulus in the learning process. Gijselaers further proposes ways for improving problem-based learning. These include the role of the tutor as an effective mediator in discussions that help activate existing knowledge by allowing brainstorming while at the same time ensuring that important issues are raised and effective problem design for promoting knowledge development, motivation, and self-study. The following image provides an overview of problem-based learning approaches based on the discussion in this section.

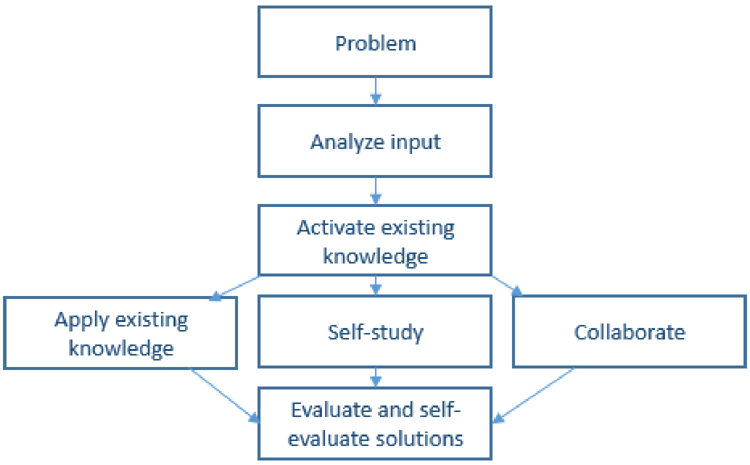


Figure 25. Problem-based learning processes.

The fact that problem-based learning is beginning to be applied in much wider contexts that those of its initial purpose of facilitating medical training is observed by researchers including White (2001) [133]. The reasons given in relation to the adoption of PBL to other sectors such as undergraduate education include the need to introduce alternative instructional methods in order to effectively address the large amount of content delivered in lectures as well as the need to build skills related to communication, computation, technological literacy, and information retrieval as well as to effectively apply these skills in contexts outside of the classroom.

2.6.4 Inquiry-based learning

Inquiring-based learning is a process that starts with a question, a problem, or a scenario. It is learner driven in the sense that the learning process is owned by the learner and it evolves with the guidance of a facilitator, i.e. a teacher. According to Bill Hutchings of the University of Manchester, in inquiry-based learning (or enquiry-based learning) students build knowledge through a process of active, self-directed learning in which they decide the appropriate approach for addressing the given scenario [134]. Scenarios and problems that instigate the learning process are often open-ended, meaning that in many cases there is not one single approach to synthesizing a solution to a problem, that in many cases there may be more than one solution, and that in other cases there may be no solution at all. The problems posed in inquiry-based learning are often complex, multi-disciplinary, and require students to seek knowledge in unfamiliar areas extending their area of engagement. In many cases, inquiry-based learning requires the students to pose their own questions thus taking the research in diverse areas related to their interests. In this respect, inquiry based learning can be, according to Hutchings, ‘a powerful instigator of complex learning’.

According to John Savery (2006) inquiry-based learning is often used in science education [127]. Savery defines inquiry-based learning as ‘a user centered, active learning approach focused on questioning, critical thinking, and problem solving’. Savery further argues that the main difference between inquiry-based and problem-based learning is the role of the tutor who acts as a ‘facilitator of learning and provider of information’.

Inquiry-based learning may involve a wide range of activities depending on the level of student engagement and experience. These may include [134]:

- Formulating appropriate questions
- Identifying key issues
- Researching for evidence; interpreting, assessing, and applying evidence to the issue at hand
- Presenting coherently conclusions, either final or tentative
- Reflecting on and assessing the learning process

Inquiry-based learning is similar to problem-based learning. As discussed above, problem-based learning has its roots in clinical investigation. Inquiry-based learning is a wider, holistic approach in which open ended teaching techniques and self-direction in learning play an important role.

Inquiry-based learning as a knowledge-building process should not be confused with scientific inquiry. The latter according to Kyle (1990) [135] is ‘a systematic and investigative performance ability incorporating unrestrained thinking capabilities after a person has acquired a broad, critical knowledge of the particular subject matter through formal teaching processes. This is contrasted to open-ended learning that is the core of inquiry-based learning processes. In other words, scientific inquiry is a process that, unlike inquiry-based learning, follows formal instruction.

2.6.5 Debate on traditional instruction-led and emerging active approaches

As a conclusion to the above discussion on emerging learning approaches, this section provides some insight on scientific debate on the effectiveness of traditional, instruction-led approaches and active, problem-based, experiential, and inquiry-based learning. Paul Kirshner, John Sweller, and Richard Clark (2010) [136] published interesting research in which they argue that minimal guidance approaches based on constructivist, discovery, problem-based, experiential, and inquiry-based teaching are not in-line will well accepted cognitive theories that debate that the cognitive architecture of the human mind is strong based on the model of long-term memory and working memory and that learning is ‘defined as change on long-term memory’. According to Kirshner et al perceptions on the role of long-term memory have altered over the past decades and ‘long-term memory is now viewed as the central, dominant structure of human cognition'. Extrapolating on research conducted by Egan and Schartz (1979) [137], Jeffries, Turner, Polson, and Atwood (1981) [138], and Sweller and Cooper (1985) [139] argue that 'expert problem solvers derive their skills by drawing on the extensive experience stored in their long-term memory and then quickly select and apply the best procedures for solving problems. The fact … emphasizes the importance of long-term memory to cognition'. The researchers argue that 'problem-based searches makes heavy demands on working memory' during which 'it is not available and cannot be used to learn; indeed, it is possible to search for extended periods of time with quite minimal alternations to long-term memory'. Traditional instruction, which is based on rehearsal, aims at storing newly development knowledge in long-term memory. Summarizing, this school of thought seems to advocate that minimal guidance constructivism approaches do not effectively promote cognitive development as this is defined by well accepted approaches, namely as the transfer of knowledge from short-term to long-term memory; they advocate that this may be the result of active learning approaches not being sufficiently proven to contribute to this transfer of knowledge from short to to long-term memory.

Cindy Hmelo-Silver, Ravit Golan Duncan, and Clark A. Chinn (2007) [140] argue that the problem in the above argument is that 'inquiry-learning and problem-based learning approaches are highly scaffolded'. They employ scaffolding extensively whereby 'reducing the cognitive load and allowing students to learn in complex domains'. At the same time these approaches contribute to the achievement of 'important roles of education that include content knowledge, epistemic practices, and soft skills such as collaboration and self-directed learning'. Hmelo-Silver et al argue that inquiry-learning and problem-based learning inherently introduce instructor guidance and as such cannot be characterized as 'minimally guided instructional approaches'. According to Hmelo-Silver et al, the scaffolding process that is inherent in inquiry-learning and problem-based learning results in the reduction of cognitive load and provides strong guidance for students. This school of thought seems to advocate that active learning approaches offer benefits in terms of scaffolding of knowledge; it further advocates that active learning offers sufficient direction and as such cannot be categorized as minimally guided approaches, which have received criticism for their effectiveness.

2.7 Gamification in learning

Gamification refers to the use of games and game mechanics in non-game contexts for engaging users in skill development [141]. Game mechanics used for educational purposes may include a number of schemes or combinations of those such as:

- The collection of badges upon the successful completion of a task
- Gaining access to additional educational levels or activities upon completion of certain tasks
- Assuming new roles upon completion of certain tasks or achievement of a specific level of knowledge; for example, users may become mentors to others upon completing a set of activities
- Group collaboration
- Competition elements between individuals or groups
- Gaining recognition through scoreboards or a "hall of fame" upon completing certain activities or tasks
- Social sharing of achievements

Another approach applied when deploying gamification for corporate training is the use of "bite-sized learning". This refers to the development of learning content, such as videos or other that a user can review in a few minutes in between other professional tasks or in breaks from work activities. However, this approach should be used as part of broader learning experiences and not standalone.

The deployment of gamification principles for educational purposes has been consistently growing over the past few years. Gamification is gaining ground in the context of corporate education. According to an article published by Meister in the Harvard Business Review blogs, research firm Gartner Inc. predicts that gamification will be used in 25% of redesigned business processes by 2015 [20]. According to the same company, gamification of business processes will grow into a $2.8b business by 2016; 70% of Global 2000 businesses were expected to be managing at least one "gamified" application or system by 2014.

According to the same article, Deloitte is a good example of a company that has successfully used gamification to increase engagement of staff, even at the highest levels, in educational processes. The idea behind the Deloitte project was to motivate employees to engage in skill building activities on-line at off-hours rather than, for example, watching television. This objective was achieved through the introduction of gamification elements into the on-line training system of the company which includes in-depth content, videos, and self-assessments. The gaming elements, which included gaining badges, assuming roles, having better opportunity to be the best in a leadership board that is reset on a weekly basis, gaining access to new content upon achieving certain learning objectives, and surprise badges that users did not expect, succeeded in engaging over 20.000 executive users since its inception in 2008.

Another example of gamification practices for building employee skills is the BeeBlock portal used by the Applebee's® restaurant chain through which the employee of the month is determined. The service allows employees to review their profile, missions, recent activity, and leaderboards through a mobile phone. Employees can log into the site while at work or at off-hours to see how they gain points and how their co-workers gain points. An innovative aspect of the gamification approach is customizing leaderboards in terms of duration. This was considered important to allow employees that work part time, and thus could not be at the top of the list in the all-time leaderboard, to be winners in smaller timeframes [142].

Gamification in lifelong learning contexts, including professional training, is observed as early as in the 1970s. Charles Coonradt introduced the concept of Game of Work® [143], which he later documented into a book in 1984 [144]. Coonradt observed that individuals who considered their work to be a burden left the office at exact 5pm but spent large amounts of time on sports. This led to the idea of bringing the gaming aspect of sports into the workplace for reinforcing the waning productivity in the U.S. Cooradt defines the following as principles of gamification at work: clearly defined goals, better scorekeeping and scoreboards, more frequent feedback, a higher degree of personal choice of methods, and consistent coaching. This approach has since been applied to the work processes of several companies for promoting employee engagement and satisfaction.

2.8 Methodologies for evaluating the impact of serious games

This chapter provides an analysis of frameworks for evaluating serious games in education. It closes with the proposal of a specific framework for evaluating the impact of programming games towards the development of critical and analytical thinking mindsets among primary education learners.

2.8.1 Qualitative evaluation models

According to Merriam (1999) [145] qualitative evaluation models are based on the idea that ‘meaning is socially constructed by individuals in interaction with their world’. The world is not a fixed phenomenon and ‘there are multiple constructions and interpretations of the reality that are in flux of that change over time. Qualitative researchers are interested in understanding what those interaction are at a particular point in time and in a particular context’. Qualitative research definitions and design may vary according to the discipline that it is applied to. According to Yin (2011) [146], too narrow a definition may exclude certain disciplines; too broad a definition may be vague. According to the same researcher, qualitative research has certain characteristics: it aims to investigate why and how a decision is made, examine views and perspectives, contribute insights into existing or emerging concepts, explain social behavior, integrate multiple sources of evidence, and more. Qualitative research is deployed when the question in focus cannot be replied by a simple yes or no answer but involves individuals’ perceptions and attitudes. According to Creswell (2003), sited by Clarke (2005) [147] qualitative research is constructivist, naturalistic, and interpretive [148].

According to Yin there are many different methods that independently or combined are used in the context of qualitative research. The ones that are more relevant to this work include:

- Case studies, in which a phenomenon is studied in its real-world context [149] [150]
- Action research, which emphasizes the adoption of an action role of the researcher or active collaboration of participants [111] [151]
- Participant-observer study, which is related to conducting field-based research based on the researcher being in the real-world setting being evaluated and studied [152]
- Phenomenological study, which focuses on studying human events as they are experienced in real-world settings [153]
- Narrative inquiry, which refers to constructing a narrative rendition of findings from a real-world setting and participants [154]

Other qualitative research methods that are less relevant in the context of this work include ethnomethodology, ethnography, grounded theory, and life history.

On the other hand, Iosifidis [155] introduces in his research qualitative and data analysis evaluation models in the context of social sciences. Important aspects include the starting point of the qualitative research, the identification of the research question (s), the description of the research tools, the establishment of connections between research and practical applications. Similarly to Yin, Iosifidis identifies important tools for qualitative research as being the following:

- Participatory observation, which is referred to by Yin as participant-observer study
- Interviews
- Biographical analysis
- Historical comparative methods
- Analysis of content
- Case studies, also referred to by Yin
- Research through user groups

There is no agreement among researchers as to whether qualitative research should be designed ahead of data collection [146]. Some researchers do design ahead of time and some no, while others choose to focus on specific design features ahead of time but not others. The design process for qualitative research is typically recursive. According to Robson (2011) [156] research designs are flexible rather than fixed.

However, Iosifidis introduces a model for structuring qualitative research that is used as the basis and background of this work. Iosifidis suggests that research design should include the following:

- Identifying the learning objective
- Identifying specific learning outcomes
- Defining the context of evaluation
- Specifying the participant group
- Taking into account pedagogical considerations
- Defining the tools that will be used in the evaluation process
- Identifying an overall evaluation approach

Qualitative research can be used in the context of wider methods that combine sources of data. Qualitative research can be used in conjunction with quantitative approaches in a single study through triangulation of results. Following is a description of quantitative evaluation approaches.

2.8.2 Quantitative evaluation models

In contrast to qualitative research, which produces data in the form of prose or texts, quantitative evaluation produces data in the form of numbers. According to Given (2008) [157], quantitative research deploys statistical, numerical, or computational techniques. Aliaga and Gunderson (2000) [158] define quantitative research as 'explaining phenomena by collecting numerical data that are analyzed using mathematically based methods (in particular statistics)'. Creswell (2003) [148] cited by Clarke (2005) [147] describes quantitative research as traditional, positivist, post-positivist, and experimental. Positivism reflects the viewpoint that quantitative research is based on the claim that 'the truth is out there' and the job of the researcher is to use objective methods to discover it, as described by Muijs (2010) [159]. Post-positivism refers to the thinking after positivism recognizing the fact that 'we cannot be positive about our claims and knowledge when studying the behavior and actions of humans' (Creswell, 2005). Post-positivism 'challenges the traditional notion of the absolute truth of knowledge' (Phillips and Budbules, 2000) [160] cited by Creswell (2005). It refers mostly to problems in which the causes that influence outcomes must be studied.

Quantitative research begins with a specific hypothesis that addresses one issue. It is largely executed through user input surveys or questionnaires in which respondents select answers to questions from pre-defined choices. Other models of quantitative research may include demographics, anthropometrics, standardized tests, numerical collection, and structural testing. Implementation of the selected methodology is flexible as questionnaires, surveys, or other tools may be distributed face-to-face, via post, or over the Internet, while answers may also be solicited by phone.

Given that quantitative research relies on statistical analysis, it is important to ensure effective cross section of respondents and a high enough participation for statistical analysis to be meaningful.

2.8.3 Multi method research and triangulation of research results

The combination of research methodologies in a specific study is generally referred to as triangulation. Different approaches on triangulation may be pursued depending on the nature of research conducted. On the one hand, diverse data sources may be used with the same framework of research. For example, different types of quantitative data in the form of surveys or questionnaires can be combined. On the other hand, data sources may be used across frameworks. Qualitative and quantitative data may be used in combination to reach research conclusions. For example, quantitative surveys and in-depth qualitative interviews can be used for cross-evaluating findings.

According to Clarke (2005), triangulation of research data is used for adding an extra level of assurance that 'any bias inherent in a particular data source … would be neutralized when used in conjunction with other data' [147]. However, according to the same researcher greater independence of research results due to triangulation is not guaranteed but, rather, is an assumption. Other reasons for pursuing triangulation of research results include complementarity of data, alleviation of contradictions that may emerge during research, and expansion of scope and breadth of a study.

2.8.4 Evaluation models for establishing the learning impact of serious games

The above general evaluation models can be enriched through evaluation approaches designed specifically for the establishment of the learning benefits of serious games. Research in educational gaming and evaluation exists widely in disciplines of medical education and business management [161]. It is further applied in the context of military training. In problem-based learning, which is central in this work, the problem drives the learning, i.e. learners are exposed to a problem before the learning begins.

Evaluation of games in educational contexts aims to provide information as to how games can be effectively integrated into curricula, teaching, and learning practices taking into account particularities of specific subjects. These models, according to Wideman (2009) may help teachers decide which game to use and why as well as what pedagogical method to apply to support learning. In earlier work by Kerriemuir overreliance to methods for evaluating games for entertainment had been observed [74] [75].

Since 2004, significant research has taken place in the area of designing frameworks for the evaluation of educational games. Earlier work focused on the evaluation of information and communication technology in learning.

The CIAO! Model [162] developed by the Open University in the United Kingdom documents the context of use of technology, interactions of students and technology, and the attribution of learning outcomes to technology taking into account both cognitive and affective learning outcomes, namely changes in perceptions and attitudes. The data used is, respectively, the designer’s aims and policy documents, records of student interaction such as diaries and on-line logs, and measures of learning including changes in attitudes and perceptions. The methods used, respectively again, are interviews with designers, observation, diaries, and video/audio recording for documenting interactions, and interviews, questionnaires, and tests for establishing increase of knowledge and change of attitudes.

The Flashlight evaluation framework developed by the Teaching, Learning, and Technology group (TLT) introduced a methodology for evaluating educational uses of technology [163]. The approach deploys focused and specific questions as opposed to vague and global. It is a formative approach that focuses on improving evaluation results as opposed to the summative model that focuses on deciding whether something has succeeded or failed. It further focuses on **qualitative changes** in outcomes as opposed to only quantitative changes. The approach further recommends studying **what users do repeatedly** with technology, which is seen as the element that influences and impacts the learning processes. That is, the Flashlight method does not look at technology per se but rather at technology as an educational tool. Flashlight further focuses on why an activity unfolded in a specific way as a means for understanding how to change the activity for the greater benefit of learners. Flashlight includes steps in the evaluation process on comparing the activity on focus with the strongest competitor, in other words what technology would be used if the one chosen was not available. Being brave to face results that are not the ones hoped for is also part of the Flashlight evaluation approach.

The Perspectives Interactions Paradigm introduced by Squires and McDougal [164] proposes an evaluation methodology for choosing educational software that takes into account the views of teachers, students, and software articulating an holistic awareness of educational issues related to the use of a given software application in specific educational settings.

de Freitas (2006) [66] discussed an evaluation framework for using games in education that takes into account four dimensions:

- Pedagogic considerations, i.e. learning models used, approaches taken, etc.
- Learner specifications, i.e. learner profile, pathways, learning background, group profile, etc.
- Context, i.e. classroom-based evaluation, outdoors evaluation, available equipment, technical support, etc. In addition, resources and tools must be taken into account
- Mode of representation, i.e. fidelity, interactivity, immersion, etc.

Emerging work by Dockerman on the evaluation of educational games at the Harvard Graduate School of Education [165] introduces a validation methodology that was applied towards the evaluation of math games, and as a result is related to this work. Dockerman defined a 5 step process through which teachers can evaluate educational games with their students:

- Define learning objectives, if possibly using standards, for example math standards for each educational level
- Describe the learning mechanic, i.e. actions that we want students to take that will reinforce the learning objective. If learning objective is speed, then we need a timer
- Imaging what students are thinking, which is one of the most critical element of application design and evaluation
- Pick a gaming mechanic, which could be selected from a wide range of options [166] and dynamics. Examples include levels, countdowns, bonuses, behaviors, points, ownership, lotteries, progression, quests, reward schedules, status, and a lot more
- Create a theme, namely the space in which the evaluation will take place. This could include the actual gaming environment that will be used in the evaluation process

2.8.5 Evaluation models tailored for working with children

When working with children, evaluation methods must be adapted. Often, it is difficult to know what will happen during an evaluation session according to Wolmet Barendregt and Mathilde Bekker (2013) [167]. It is further difficult to know how much the teacher influences learners when presenting instructions or how much groups working in the same room influence each other. Furthermore, learners today are exposed to educational games as well as digital games and services for entertainment which further influence their game play and outcomes.

To help children express themselves during evaluation activities, researchers use wider feedback mechanisms. For example, Bieke Zaman proposes the 'thinking out loud' method [168], which is in line with David Dockerman's method described above. Other methodologies include drawing interventions suggested by Barendregt and Bekker (2013) [167] that help children express themselves without verbalizing.

2.8.6 On choosing a research methodology

Several factors influence the choice of a specific research methodology, qualitative or quantitative. Creswell (2003) [148] identifies the following:

- The world view of each paradigm; qualitative research reflects viewpoints that the world is subjective while quantitative research is based on the hypothesis that the truth is objective
- The personal experiences of the researcher in relation to the tools to be deployed. For example, a researcher more experienced in statistical analysis may choose quantitative models while another exposed to literary reviews may choose qualitative
- The nature of the problem. For example, when the research question refers to factors that influence outcomes then quantitative models are more appropriate. When the important variables of a problem are not known or when a problem has been little studied qualitative approaches may be more suitable
- The target audience of the study, or, in other words the audience that the results address

Other factors that may lead to choosing qualitative models [147] include a requirement of researcher interaction with what is being researched, a study question that involves values, an expectation that decisions and results may evolve during the research process, a significance of context, and more.

Factors that may lead to choosing quantitative models include a research problem in focus that dictates that the researcher is independent from what is being researched, results that are expected to be value-free and unbiased, a research question that is based on definitions and can be answered formally and impersonally, a cause and effect relationship in the research question and expected results, a static research question for which result categories are fully identified before the research starts, and more.

3 Design and evaluation of a game-based framework for building early analytical and critical thinking skills through programming concepts

This section presents the design of a framework for improving the analytical and algorithmic skills of young learners in primary education and specifically learners aged 10 to 12 years. This work also presents the evaluation of the framework through the engagement of learners in real-life learning experiments taking place in blended learning contexts.

3.1 Summary of what we know

The theoretical analysis and review of past research presented in section 2 leads to certain observations. There are clear indications, reflected in EU policies and strategies on education, training, and development, that analytical thinking is a transversal skill that will be increasingly in demand in the coming years in innovation related sectors that are expected to drive economic growth.

Programming is not currently widely deployed in general direction school curricula. Only in the final grades of upper secondary high schools do learners get exposed to programming concepts; furthermore, the learners that do get exposed to programming are the ones that aim to choose STEM and engineering related study paths in higher education. However, initiatives are beginning to take shape in specific countries through which programming will be integrated in school curricula to help alleviate skill mismatches in today’s knowledge economy. These initiatives are often designed through collaboration between educational authorities and industry.

Currently, learners may get exposed to programming through informal learning initiatives that do not take place in the context of formal school curricula and thus do not address the entire student body. Such initiatives may deploy tools and platforms, such as Scratch® and others, which have been developed with the objective of promoting programming skills.

Serious games and gamification may offer learning benefits in formal and informal training processes. The way games are integrated into wider, iterative learning processes that help eliminate the risk of random selections may affect learning outcomes.

3.2 Problem statement

Programming is an inherently analytical process. The most important aspect of programming is developing an algorithm; in other words a precise, accurate solution to a problem that can be executed in a specific amount of time by following well defined steps.

Reaching a correct algorithm involves structured thinking. By the time a learner is able to write a program that implements an algorithm the learner has already mentally solved the problem. Introducing a series of instructions that explains to someone else, in this case the computer that does not possess intelligence but only executes commands, how to implement an algorithm implies that the learner fully understands the underlying solution and is able to elaborate on it and to document it.

Algorithmic thinking is rooted in universal logic that is present in all cultures. An educational approach that deploys algorithms towards building logical thinking is, for this reason, naturally inclusive. It can be adapted to diverse educational environments engaging learners with varying learning needs. It can be personalized in terms of content, intensity, and focus to meet individual educational goals through the appropriate selection of exercises.

Analysis in the context of programming practices involves identifying implementation goals, understanding the resources available for building a solution, breaking down a problem into smaller parts, solving those, and synthesizing a solution based on the smaller components. This activity promotes the development of wide problem-solving skills. Functional programming helps learners identify in an analytical manner repeating sequences of actions that can be replaced by a function in a code segment making the solution more coherent and easier to read and understand. Using programming constructs such as loops helps develop more elegant solutions to a given exercise. On the other hand, object-oriented programming introduces an organization to thinking patterns that is useful for addressing high levels of complexity. Learners in ICT ultimately get exposed to these programming paradigms; they benefit by developing high level problem solving skills.

Algorithmic thinking itself plays a central role in programming education. Learners become familiar with algorithmic patterns that can solve broad categories of logical exercises. Examples of such well known algorithms include divide-and-conquer and reduce-and-conquer, which involve breaking down a problem into smaller instances and tackling those. As a result of the wide applicability of the above thinking frameworks, ICT students become familiar with them early on and refer to them for synthesizing solutions throughout their professional careers.

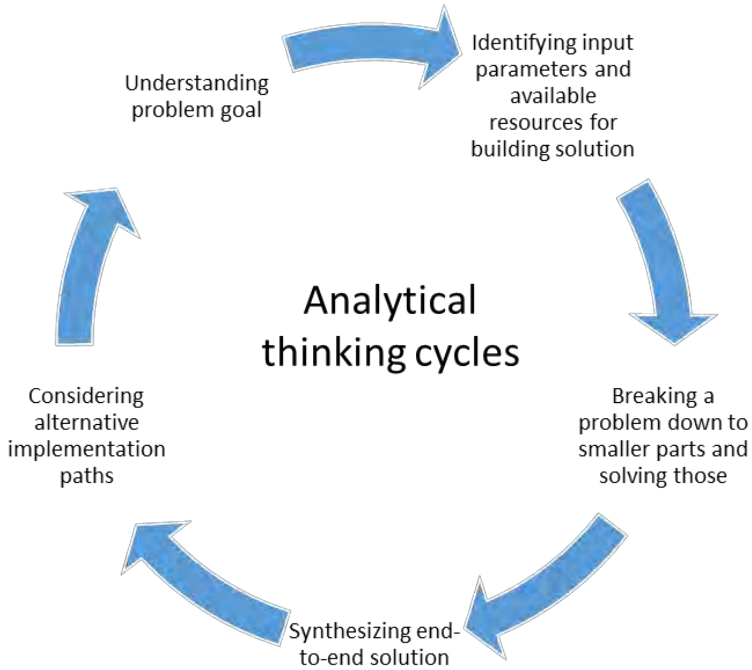


Figure 26. Cycles of analytical skill building under focus in this work.

Algorithms, programming, and logic are interrelated concepts. This work evaluates how programming, which is inherently structured in nature, can be deployed as a game for promoting engagement with learning processes related to analytical skill building and how it can promote the development of problem solving skills.

Synthesizing a program that solves a specific exercise requires learners to take part into activities that are inherently analytical such as recognizing the objective of a given exercise, the input parameters, and the resources available for introducing a solution. By successfully completing a viable program learners build their capacity to describe in detail the solution that the program implements. Explaining consciously the solution to a given exercise is part of the analytical thinking process and demonstrates the capacity to effectively apply problem solving skills and methods. A number of questions arise on how programming, when deployed in the proposed game-based context in classroom blended learning settings that combine wider problem-solving activities can contribute to the development of analytical thinking capacity. Does gamification of programming through elements such as recognition of achievement, difficulty levels, and medals positively influence engagement in learning processes towards building analytical thinking capacity and problem solving skills? Does game-based exploration help learners build intuition on potential solutions to logical puzzles? Does game-based programming as a synthesis tool help learners accurately understand and precisely reproduce a solution to a logical puzzle and explain it to others? Does class collaboration and teacher mediation positively influence analytical thinking skill development through game-based learning design that deploys programming?

3.3 Research methodology

Taking into account the above research in broad fields, a validation framework has been designed for investigating whether and how programming games contribute to the development of algorithmic and reasoning skills by generating feedback on the above described research questions through the engagement of groups of learners and their teachers.

According to Creswell (2003) [148], the selection of a single research paradigm, qualitative or quantitative, is preferable due to the differences in the nature of the two frameworks. This includes perceptions on reality, subjective vs. objective respectively; role of values; use of language for the description of results; and overall process.

A qualitative method has been selected for this research for several reasons. The evaluation of the potential added value of serious games based on programming concepts towards building problem solving and analytical thinking capacity can benefit from interaction with learners pointing to the need to apply qualitative approaches. Feedback is not expected to be in the form of a yes or no answer given that context, i.e. how serious games are integrated into the educational process, is significant thus pointing to the higher suitability of qualitative research. Results will be documented in a descriptive manner, which points to the need of qualitative research methods. Perceptions of the participants, attitudes towards the educational process, values related to learning, and educational culture are factors that influence feedback pointing to the higher suitability of qualitative descriptions of results. The multidisciplinary nature of this work, which combines elements from computer science and learning design, also points to a higher suitability of qualitative methods. The work aims to highlight the effects of introducing emerging learning approaches into educational practices and validating the effects of these approaches. As such, the work is descriptive using observation as a means of collecting data which further points to the higher suitability of qualitative approaches (Walliman, 2006) [169]. Furthermore, the work is action oriented and is carried out in the real world; it requires the active and conscious participation of learners and their teachers in learning experiments during which serious games are deployed. The evaluation is constantly monitored and adjustments to the process are being made as appropriate in real-time. The research, including during the implementation and interpretation of results, views all participants, counting teachers and learners, as equal partners in the evaluation process. These are elements that suggest that qualitative approaches to the research are more appropriate.

The specific methodology proposed is based participatory observation during learning experiments organized with groups of primary school learners. Participatory observation is proposed in cases where this is possible, i.e. the physical presence of the researcher was possible as a result of school proximity. The approach combines elements of the framework proposed by Iosifidis [155], the game-based evaluation approach proposed by de Freitas, and ICT as an educational tool evaluation approaches. In cases when the physical presence of the researcher is not possible interviews are proposed to be conducted by the teachers with the data being conveyed in written documents. The evaluation process involves:

- The identification of learning objectives in relation to problem statement
- The description of the research context
- The design of a game-based learning platform for building analytical thinking skills by exploiting the structured nature of programming
- The identification and the description of the participant groups of learners, i.e. the sites at which data will be collected
- The description of pedagogic considerations and links to the school curricula
- The identification of a specific evaluation plan

- The collection and analysis of data through participatory observation in which the researcher is the observer and documentation of data in the form of images, videos, and texts
- The collection and analysis of data through interviews based on specific questionnaires
- Description of how findings relate to existing literature

This actual implementation of the evaluation framework that is outlined above is presented in the following section.

3.4 Programming as a serious game: the cMinds learning tool

3.4.1 Design

The cMinds programming environment differs from other efforts in the area of introducing programming to young learners.

As argued by Tsalapatas et al (2011) [170] [171] the main differentiating point of the cMinds programming environment is its objective: instead of focusing on teaching programming the tool aims at **introducing logical thinking** to young learners by **exploiting the structured nature of programming practices**. In other words, visual programming as used in the context of cMinds is a tool that helps learners think in a structured manner. At the same time visual programming provides a means for young learners for graphically presenting their solutions to a given problem; in other words, learners can use the commands to describe their solution in a step by step manner.

Other differentiating factors are related to design choices that are made for supporting the aim of the application, i.e. building logic skills. The application by design maintains the structure of programming through visual commands that all but eliminate syntax. Thus, learners are encouraged to use programming as a problem solving tool rather than having as their main goal the development of programming skills.

cMinds introduces learners to logical puzzles, many of which may be familiar to learners and teachers. The familiarity with the puzzles allows all to focus on synthesizing a solution with given programming tools and to build problem solving skills.

The cMinds environment for building analytical and algorithmic thinking skills integrates three working areas through which learners can explore, synthesize, visualize, and compare solutions. cMinds applies **experiential**, **active, and problem solving learning approaches** that encourage learners to engage in analytical thinking processes. In the proposed learning methodology, depicted in the following figure, learners become exposed to logical puzzles, build intuition on potential solutions through experimentation with elements of a given puzzle, synthesize structured solutions, receive feedback on their efforts, participate in class collaboration and debriefing, and compare solutions towards identifying the optimal one.

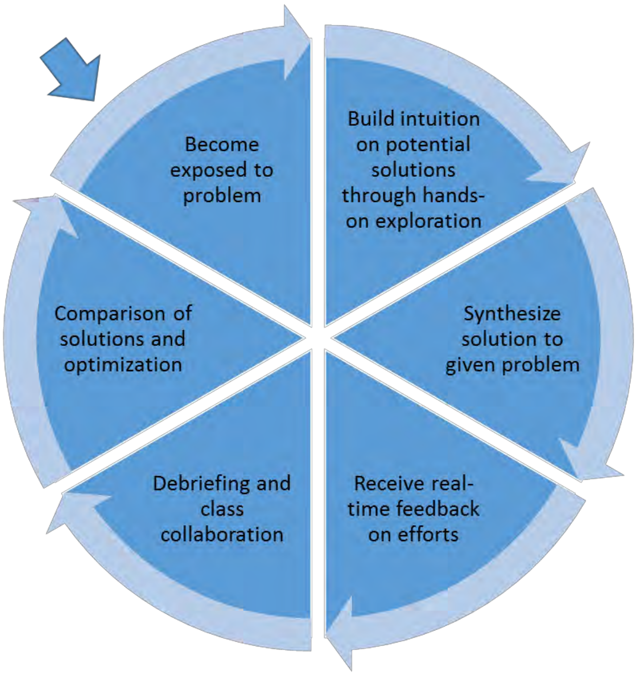


Figure 27. Game-based learning methodology design integrating active, experiential, and collaborative learning approaches.

At a practical level, the above methodology is deployed through the cMinds proof-of-concept environment, which includes three separate areas of interaction for exploring, synthesizing, and comparing as this is graphically depicted below.

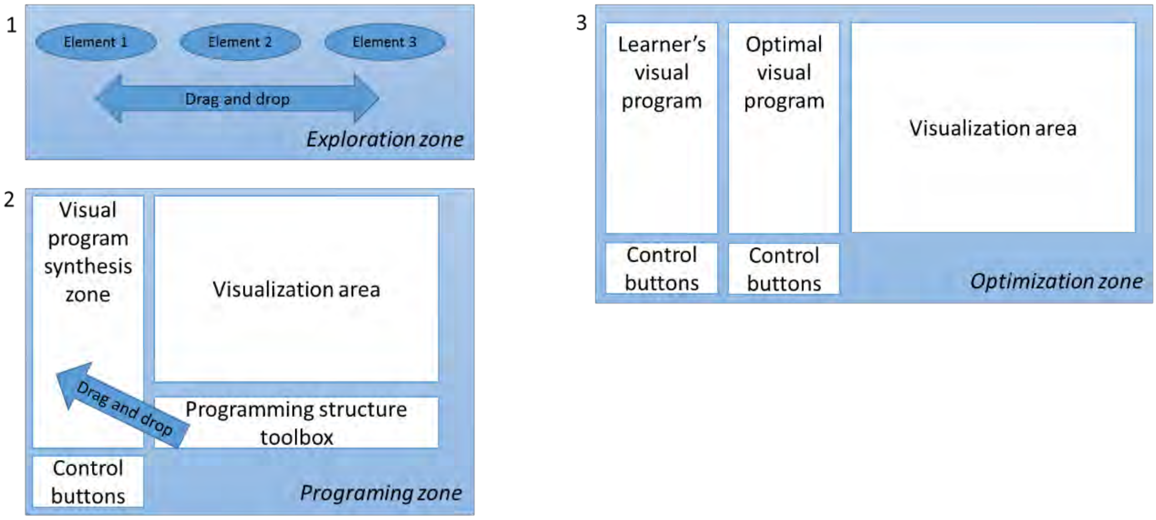


Figure 28. Overview of analytical skill building methodology in cMinds through exploration, synthesis, and solution comparison.

More specifically:

The exploration area is a semi-structured environment that aims to enable students to experiment towards building intuition on potential solutions to given exercises. In this environment students do not program. Rather, they get exposed to a microworld which, similarly to the proposal of Papert, simulates real-life, is simplified to avoid exposing learners to unnecessary "noise" that may distract them from focusing on the learning goal, and it provides all the necessary tools that enable the user to synthesize a solution. Students can drag and drop items on the screen until the given puzzle is solved. They can repeat this process until they are in a position to reproduce it consciously and to describe it to others. The following picture demonstrates the exploration zone for a logical puzzle that asks students to categorize decorated eggs into similarly decorated boxes.

Figure 29. The cMinds exploration zone.

The programming zone is the area in which students, after having built intuition on potential solutions to a given puzzle by working in the exploration zone, are encouraged to synthesize through visual programming a precise program that implements their solution. This process uses programming as a story-telling tool for explaining step-by-step to someone else, in this case the computer, the learner’s solution to a given problem. Similarly to other related software, the programming zone introduces a toolset of programming commands that are visually displayed. The users can drag and drop commands from the toolset into a programming zone for synthesizing their visual program.

The following figure demonstrates the use of the programing zone for solving a puzzle that asks learners to precisely measure specific volume of water by utilizing given water containers.

What is different from other environments, however, is that commands are completely **visually displayed** with no text involved (with the exception of a tooltip) and no initialization required. This allows the use of the software by young children you may not yet be able to read making cMinds **suitable for use by a younger target group** that those typically addressed by related environments. Users can execute their program using control buttons and get immediate feedback on their efforts through an animated visualization of the sequential execution of the commands in their program.

Figure 30. Overview of the cMinds programming environment: command toolbox (bottom right), programming zone (left), visualization zone (right), control buttons (bottom left).

The programming zone toolset supports the following command types:

- Actions-statements, to be used in a sequential visual program

- Conditionals, which can have the form of simple IF-THEN statements or IF-THEN-ELSE statements
- Case statements that constitute conditional with several options and are of the form SWITCH-IF-DO-ELSIF-DO
- Loops in the form WHILE-DO
- Conditions that can be used in the context of conditionals or loops for structuring a program

These simple commands help students build basic programs for graphically describing their solution to a given problem. The following figure demonstrates the structuring of a simple IF-THEN-ELSE statement using the graphical commands.

The statement instructs the computer, which is depicted as a robot in order to have human-like representation friendly to learners, as to when to pick an apple from an apple tree:

```
IF
        the apple is ripe
THEN
        pick the apple
ELSE
        do not pick the apple
```

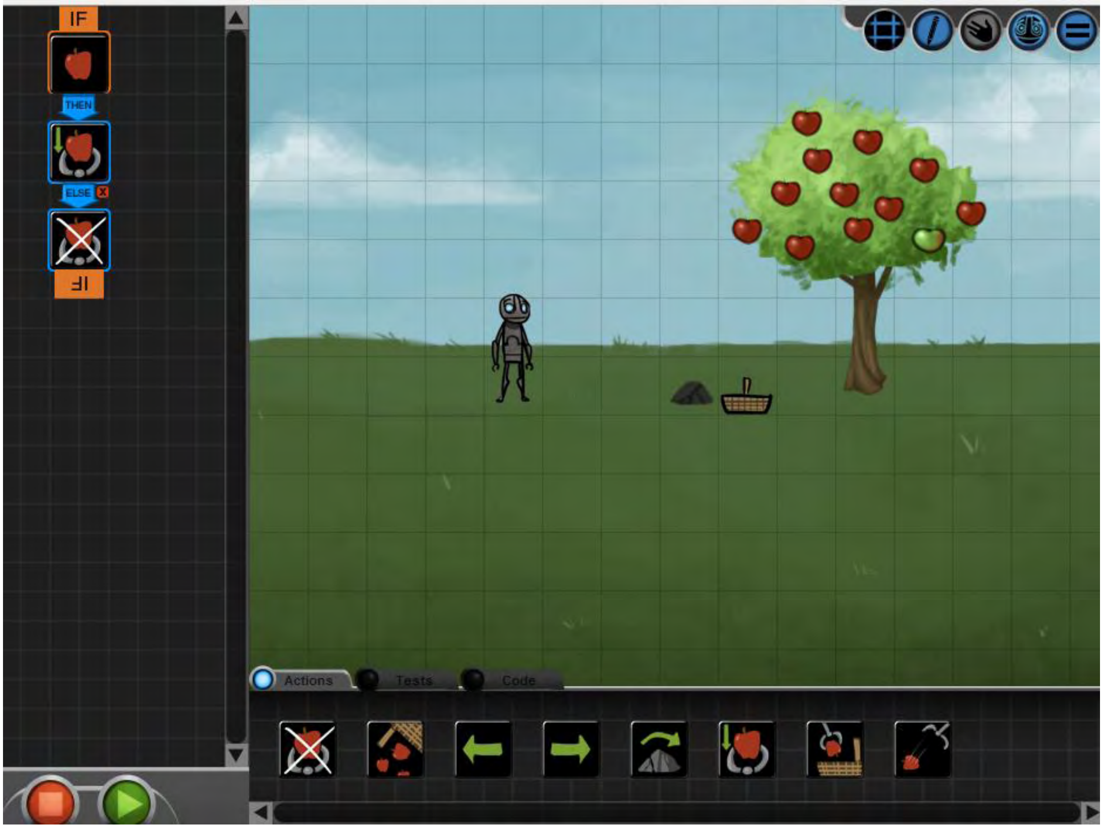


Figure 31. IF-THEN-ELSE statement structuring in cMinds.

The following figure demonstrates the deployment of a WHILE-DO command for the structuring of a loop. The command instructs the computer how to count the difference between two numbers, in other words how to perform a subtraction. The commands specifically states that while the robot has not reached the finish line it should make one step to the right. The command is the following:

WHILE
you have not reach the finish line
DO
make one step to the right

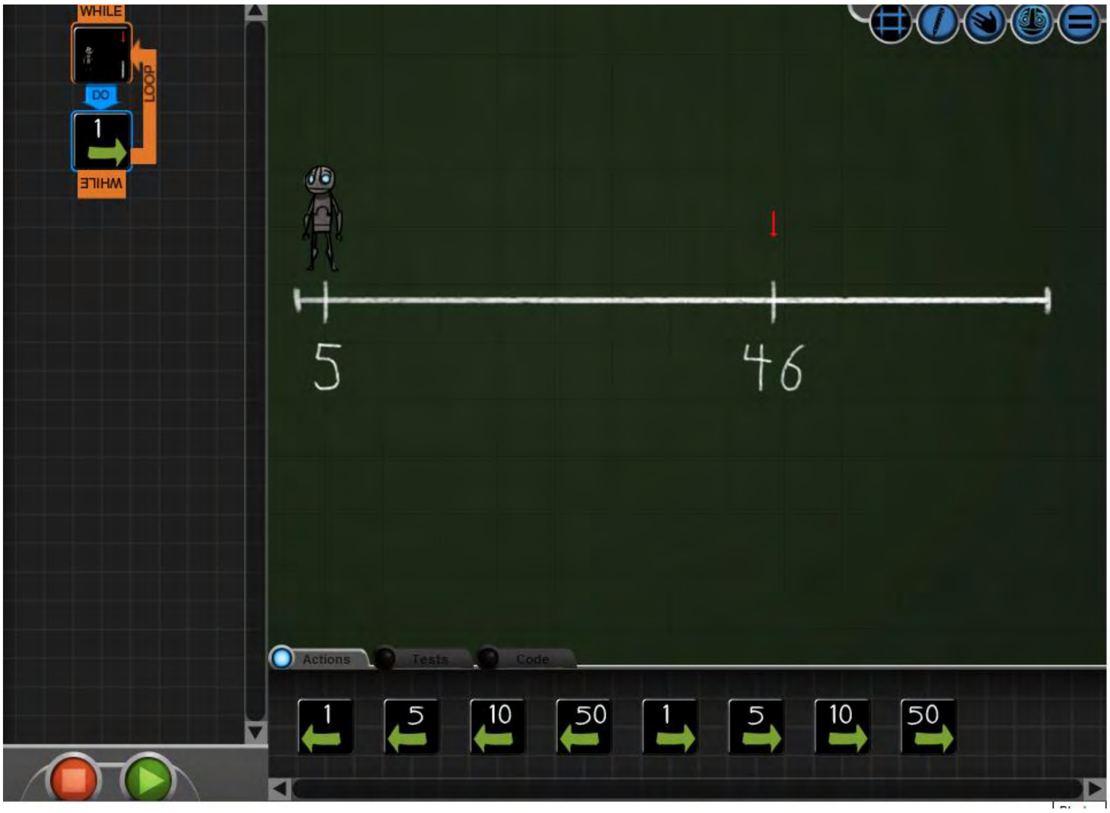


Figure 32. WHILE-DO loop statement in cMinds.

The following figure demonstrates the use of the SWITCH case command. The command instructs the computer to sort decorated eggs to boxes with the same decoration.

SWITCH on the color of the egg

IF

    the color is red

THEN

    put egg in the red box

ELSE IF

    The egg color is green

THEN

    put the egg in the green box

ELSE IF

    the egg color is blue

THEN

    put the egg in the blue box

Figure 33. SWITCH statement in cMinds.

The visualization zone is an area where learners can see an animated execution of their visual program and thus get in a graphical manner feedback on what the series of commands they introduced in the programming zone actual achieves. Through this feedback learners can correct any mistakes in their program and continue this process iteratively until they reach a working solution.

After reaching a correct solution learners can compare their program to an "optimal" one that is integrated into the application. This is achieved in **the comparison zone.** In cMinds, optimality is defined as the execution of a program through a minimum number of steps. Exposure to the notion of optimality helps learners understand that often there is not only one correct solution to a problem. It further can be exploited by the teacher for starting a conversation in the classroom on different approaches that can be followed for reaching a working solution.

Finally, cMinds introduces **game mechanics** for **promoting engagement with the learning process**. Due its importance this feature is discussed in a dedicated section below.

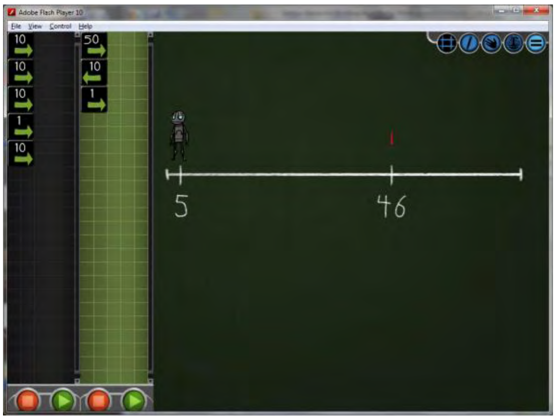


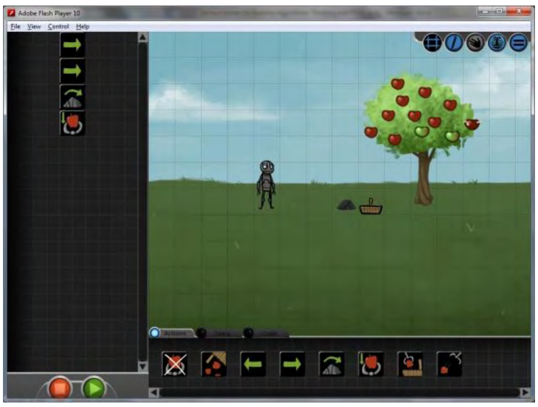
Figure 34. Comparing a correct and an optimal solution.

3.4.2 Logical puzzles

The cMinds platform first introduces learners on using basic programming constructs through the provided toolset. The constructs that are supported are: sequential commands, conditional statements (IF-THEN, IF-THEN-ELSE), loops (WHILE), and case statements (CASE). The learner is asked to apply the constructs for solving a simple exercise that is aimed as a tutorial. The exercise asks the learner to instruct a robot, which acts a human-like representation of a computer, to pick an apple from a tree taking into account specific restrictions such as obstacles that need to be overcome or conditions that need to be met.

Once the learner is comfortable with the use of the programming constructs supported by the environment she is asked to apply them towards solving a set of logical puzzle by using the exploration zone for experimenting, programming and visualization zone for synthesizing a program, and comparison zone for checking for optimality. The following puzzles are available through the environment:

The **Freezies** puzzle is a pattern matching problem in which the learner is asked to recognize a sequence in a series of shapes and reproduce it through a visual program.
The **Eggs** puzzle is a sorting problem in which the learner must sort decorated eggs into boxes that carry the same decorative pattern.
The **Water Containers** puzzle is a mathematical problem in which learners must perform operations in relation to measuring specific volume of water using 3 containers with specific capacity.
The **Math** puzzle is a mathematical activity in which learners are encouraged to perform subtraction operations through intuitive approaches that apply estimation.
The **Santa Claus** puzzle is a classic divide-and-conquer problem in which learners are asked to discover a single heavier box among otherwise identical boxes. Two implementations are support: an easier but not optimal implementation where the objective is reached by weighing 2 boxes at a time against each other and the optimal divide-and-conquer solution where half of the available boxes are weighed against the other half minimizing the execution steps.
The **River Crossing** puzzle is an instance of the classic wolf, sheep, and cabbage puzzle in which all must cross a river according to restrictions, namely that none of the subjects eats another.



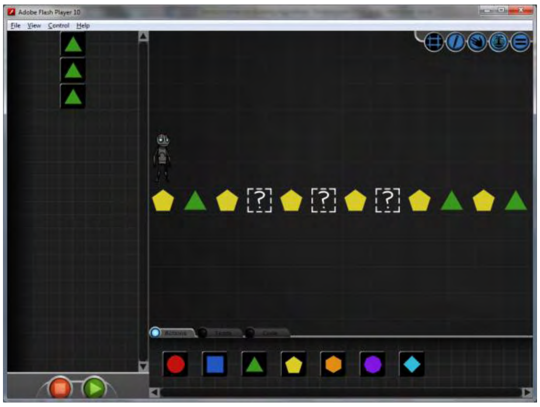


Figure 35. The Friezes puzzle (top left). The Pattern Matching puzzle (top right), the Santa Claus puzzle (bottom left), the River Crossing puzzle (bottom right).

3.4.3 Game mechanics

Game mechanics may include a number of features such as points, levels, leaderboards, badges, onboarding, challenges and quests, social engagement loops, feedback and reinforcement, and more. They exploit the natural desire of individuals for competition, achievement, status, self-expression, and closure [141].

Gamification approaches are introduced in cMinds with the objective of enhancing learner engagement with the learning process in the long-term. Gamification in cMinds enriches the sense of competition, even with oneself, and enhances the replayability of the game. Diverse gamification features are available in cMinds including challenges and quests, feedback and rewards, difficulty levels, and social engagement loops.

3.4.3.1 Challenges and quests

cMinds focuses on **solving logical puzzles**, which is an activity that all individuals like to endeavor in. With puzzles as the starting point of learner engagement cMinds introduces programming only as a tool for generating a viable solution; in other words, programming is not the main purpose of the activity but a means to an end, that of solving a problem. This is in line with starting with fun first and then introducing educational aspects into game activities.

3.4.3.2 Semi-structured exploration

The cMinds exploration zone, which is designed with the objective of promotion experimentation towards building insight on viable solutions to a given puzzle by dragging and dropping graphical elements that represent given parameters in a puzzle, offers gamification elements that resemble an arcade game. Experimentation is semi-structured as the learner must select and act on elements available on the screen towards reaching a specific goal as opposed to freely experimenting in an open-ended scenario. The experimentation offers elements that resemble how a user acts in an arcade entertainment game such as trying different approaches, which initially may be random but may lead to conscious series of steps for solving a problem through the gradual and step-wise development of understanding of possible solutions. This gaming element may be exploited in learning processes for initiating learner engagement and for easing learners into problem-solving processes for solving logical puzzles. The semi-structured exploration is designed for use by learners before they engage with visual programming as a tool for synthesizing precise solutions to the exercise at hand.

3.4.3.3 Difficulty levels

Difficulty levels are introduced in cMinds as a means of challenging the user and promoting long-term engagement with the game and, as a result, the learning process. Each logical puzzle has 5 difficulty levels. Each level corresponds to a different instance of the same logical puzzle with varied complexity. For example, in the Friezes puzzle complexity in raised by increasing the number of different shapes that appear in a sequence; in the Eggs puzzle by increasing the number of patterns that the user must sort; in the Water Jugs puzzle by raising the complexity of the mathematical solution; in the Math activity by introducing into the subtraction operation higher numbers and decimals; and so forth.

3.4.3.4 Rewards

In cMinds rewards, which in broad gamification strategies are introduced when a player achieves specific tasks, are awarded to the user upon completion of a specific level of a logical puzzle. The rewards include (see Figure 36 below):

- **“Bravo” screen**. The user sees “bravo” screen as a congratulatory conclusion upon achieving a correct solution for a specific level of a puzzle.
- **Stars**. Once the user has completed a difficulty level of a puzzle, the corresponding item is highlighted with a gold star in the main navigation screen of the game

- **Medals**. Upon completion of all 5 difficulty levels of a given puzzle the user receives a puzzle that is displayed in the main navigation screen of the game.

Figure 36. Rewards in the form of a "Bravo" screen (left) and stars and medals (right) upon completion of a difficulty level or all difficulty levels of a puzzle.

3.4.3.5 Social engagement loops

cMinds is designed for deployment in the classroom in the context of wider, blended learning activities that may integrate instruction, collaboration, and exploration. Similarly, it is designed for deployment in the context of gaming loops similar to the ones proposed by Garris (2002) [71] in which engagement with the game is part of a cycle that also involves collaboration and debriefing with the objective of reinforcing the scaffolding of knowledge.

Following the Bloom taxonomy for building higher order thinking [77] [76], cMinds promotes knowledge development and comprehension through the engagement in problem solving in the exploration zone, application through engagement in solution synthesis in the programming zone, and engagement in analysis and evaluation through collaboration among class learners after the completion of their individual exploration. In the context of collaborative class activities learners can compare solutions, describe their solution to others, and understand why a solution works or why one working solution is better than another.

3.5 Evaluating the deployment of serious games towards building algorithmic and reasoning skills

This sections describes how the research process for evaluating the added value of programming games towards building problem solving and analytical skills was implemented in the context of this work.

3.5.1 Identifying the learning objective and specific learning outcomes

The objective of this work is to investigate the impact of educational games that focus on visual programming on the development of algorithmic and analytical thinking pathways among children. The learning objective is the development of reasoning and analytical skills. In line with Bloom's model for higher order thinking the model aims to specifically evaluate:

- Ability to understand a given problem and input parameters
- Ability to synthesize an algorithmic solution for solving the given puzzle
- Ability to map the solution into a visual program
- Ability to explain, describe, and support a solution to other in a clear manner
- Ability to evaluate a solution in terms of optimality and to explain the difference between a correct and an optimal solution to a given problem based on specific criteria

3.5.2 Defining the context of evaluation

The evaluation process aims to validate the degree to which programming games when integrated into existing school practices, as opposed to being deployed as standalone tools at home or outside school practices, contributes positively towards the development of analytical thinking skills. The evaluation process extended existing school practices on the development of ICT skills among primary education learners.

Evaluation took place in the school computer laboratories under the supervision and mediation of the teacher. Children used the programming game on the lab computers in small groups. The use of the proposed virtual learning tools in the computer laboratory of the school closely follows currently applied practices for learning through digital technology.

3.5.3 Description of the participants / learners

Evaluation took place with 4 groups of children, all in primary education.

The first group involved 20 6th graders aged 11 to 12 enrolled in the 1st primary school of Volos. The second group involved 18 5th graders aged 10 to 11 enrolled in the 11th primary school of Volos. These two groups were selected with the objective of providing insight on typical capabilities, pre-existing knowledge, and aspirations of learners aged 10 to 12. The two schools are located in the town of Volos. Volos is a medium sized town of 120.000 inhabitants in central Greece whose economy is widely dependent on small businesses following deindustrialization that took place a few decades ago. Learners enrolled in the two schools are the ones whose home address is within specific proximity of the school location. This implies that learners are not selected based on performance, either higher or lower than the average for their age. Learner families are broadly middle class facing the typical challenges in the current economic environment. The above are discussed to demonstrate that the selected groups engage learners whose academic capacity is typical for their age.

The 3rd group involved 38 learners aged 9-12 enrolled in the 5th and 6th grades of the 6ZS Kolin School in the Czech Republic. Specifically, the group involved 21 children aged 9-10 years enrolled in the 5th grade and 17 children aged 11-12 years enrolled in the 6th grade. Kolin is a small town of approximately 20.000 inhabitants that lies approximately 60km east of the capital of the Czech Republic Prague. It is a public school that enrolls approximately 300 learners. Learners are enrolled to the school based on their home address following practices similar to those adopted in Greece for public school enrollment. As such, the children are representative of the population in a small town in the Czech Republic and are not selected based on particular academic performance.

The 4th group involved learners at the Economic College of Transylvania (CETTM) located at Targu Mures, Romania. Targu Mures is a town of approximately 134.000 inhabitants in central Romania. The school enrolls 536 learners aged 3-15. Students are organized in three broad educational programs: children 3-6 are enrolled in the kindergarten program, children aged 7-11 are enrolled in the primary program, and children aged 12-15 are enrolled in the lower secondary program. A total of 75 students were engaged in the activities. The students engaged were aged 8-11 years.

Similarly to the groups presented above, learners enrolled in this school based on the address of their home and as such are representative of the general population in their town with normal academic performance.

3.5.4 Pedagogic considerations and links to school curricula

3.5.4.1 In Greece

In Greece work was organized for implementation in the school curriculum “free zone”, which corresponds to specific hours in the weekly school program during which the teacher is free to apply activities that are not explicitly defined in the school curricula but ideally are related to school activities and demonstrate a link between school and real-life. In this context, the evaluation of game-based learning activities that focus on digital and transversal, analytical skill development that are in high demand in the real world was highly relevant.

The activity was related to STEM and informatics school curricula thus providing direct added value to existing school activities through the integration of technology. Following is an overview of mathematics and science school curricula, which is provided for establishing links between the proposed activities and existing school practices [172].

- In grade 1 learners are exposed to numbers up to 100, operations, empirical geometry, and problem solving
- In grade 2 learners are exposed to numbers up to 1000, operations, geometry including the recognition, description, and drawing of shapes, and problem solving
- In grade 3 learners are exposed to numbers up to 10.000, operations, decimal numbers, measuring of shapes, time, and volume, and geometric shapes including operation on those
- In grade 4 learners are exposed to numbers up to 1.000.000, operations, operations on decimals, shape and pattern recognition, data collection and organization, and the concept of probability
- In grade 5 learners are exposed to numbers up to 1.000.000.000, decimals, operations on natural numbers, measuring units, drawing and recognizing

geometrical shapes, data collection and organization, mean values, and probabilities

- In grade 6 learners get exposed to natural and decimal numbers and all related operations, measuring units, shape area calculations, complex numbers, data collection, identification of problem input parameters, rule-based descriptions of pattern shapes, mean values, analogies, and equations

On the other hand, following is a list of objectives of informatics curricula for primary education [173]:

In grades 1 and 2 learners build knowledge on:

- Using the computer
- Expressing ideas and being creative through drawing
- Using a word processor
- Becoming familiar with the Internet
- Modeling conceptual maps
- Performing projects on the above

In grades 3 and 4 learners build knowledge on:

- Using the computer
- Expressing ideas and being creative through presentations and multimedia
- Expressing ideas and being creative through drawing
- Using a word processor
- Becoming familiar with the Internet
- Modeling conceptual maps
- Performing projects on the above

In grade 5 learners build knowledge on:

- Using a word processor
- Expressing ideas and being creative through presentations and multimedia
- Collaborating through informatics services and tools
- Solving problems using spreadsheets
- Programming the computer
- Performing projects on the above

In grade 6 learners build knowledge on:

- Using a word processor
- Expressing ideas and being creative through presentations and multimedia
- Solving problems using spreadsheets
- Programming the computer
- Performing projects on the above

The above demonstrate that learners get exposed to programming concepts in late primary school, and specifically in the 5th and 6th grade. Learners become exposed to programming in a LOGO-like environment. Practical challenges faced by teachers and learners include limited access to a computer lab, lack of technical support, old equipment, and lack of training. In relation to collaboration, learners typically use the school computers in small groups of 2 or 3 mostly due to the fact that the learners in a typical class are more in number than the available computers. The level of collaboration in the classroom is largely dependent on the individual teacher practices, experience, level, background, and interests.

The above demonstrate a link between the proposed game-based learning activities and school curricula in Greece, which enabled an easy integration of the proposed active learning methodologies and supporting tools, i.e. cMinds, into classroom activities. The proposed cMinds game-based programming environment enabled learners to focus on solution synthesis and less on programming issues, for example correct syntax, through visual representations of commands. As a result, emphasis was placed on the logical thinking process.

3.5.4.2 In the Czech Republic

Primary schools in the Czech Republic enroll learners aged between 6 and 15 years in 9 grades that are separated broadly in two educational programs, one for learners aged 6-11 and one for learners aged 11-15. In lower grades there is a strong focus of school curricula to language, literature, mathematics, arts, crafts, physical education, English, and also information technology. In upper grades additional subjects are introduced including civics, biology, science, and a second foreign language. Information technology is also taught in upper grades.

Information technology focuses mostly on familiarization with ICT equipment and software through use of common tools for accessing through the Internet information and for processing information (e.g. word processors, media processors, presentation building tools, and more). In relation to introducing ICT-related activities in classrooms the biggest challenge is a need for upgrading related teacher skills. Over the past decade a new teacher training program titled “The School of the 21st Century” aims at building teacher skills, including analytical thinking skills. In the context of these seminars teachers build basic computer literacy skills that they next use in their classrooms. Teachers may choose from a wide range of offered training seminars. Many do not choose to follow ICT training courses mostly due to limitations on the number of seminars that they are allowed to attend and perceptions that other topics, such as addressing bullying, are of higher importance [13].

3.5.4.3 In Romania

According to the European Schoolnet Survery on ICT in Education, in Romania steering documents on ICT learning objectives in schools exist only at the secondary education level. Even there, there are no steering recommendations for teaching programming [13]. Thus, ICT is taught in secondary schools as a general tool to be used in the context of other subjects. In primary education, similarly to practices in other countries, ICT learning programs focus on becoming familiar with computer equipment and software, including e-book readers, communication software, multimedia applications, office applications, and applications for reviewing digital resources [174].

3.5.5 Tools

The research process for evaluating the contribution of programming games towards the development of analytical thinking processes among primary education learners was carried out by deploying the cMinds programming environment. The environment was selected for a number of reasons. First, the environment has been designed and developed with an objective that is directly linked to this research: to use visual programming as a means for building analytical and critical thinking capacity in early childhood education. The environment introduces gaming elements that are exploited in this work to investigate whether, how, and in what context serious games based on programming can help learners engaged in wider blended learning activities build algorithmic and reasoning capacity. These gaming elements in the form of rewards, semi-structured exploration, alternation between exploration and visual programming, and a heavily visual representation of programming commands that exploits programming structure and all but eliminates syntax through visual presentations of commands are not available in many other related tools. In addition, the environment introduces a certain degree of direction to learners that can be exploited for designing learning activities in a manner that avoid random choices during gaming activities while at the same time it provides hints to learners for gradually building intuition on potential viable solutions to a given puzzle. The environment is children friendly and has been designed with the specific target group of this work in mind. Furthermore, it has been designed for deployment in class in the context of wider learning process as opposed for standalone use at home. This differentiates the cMinds environment from off-the-shelf software packages designed for entertainment or as complementary to school work learning tools.

3.5.6 The evaluation plan

The proposed evaluation of the potential added value of serious games based on programming for the development of early analytical thinking skills was planned as a case study to be implemented as a **learning experiment** a term used to describe a carefully designed learning activity taking place in the classroom under teacher mediation. The learners of the schools described above, namely the 1st and 11th primary schools in Volos, Greece, 6 ZS Kolin in the Czech Republic, and CETTM, Romania, and their teachers participated in the activities that took place in the fall of 2012 as well as May and June 2013. The activities were organized as follows:

Step 1, teacher briefing: briefing the teachers on the objective of the proposed evaluation was considered important for achieving their consent. The briefing aimed at exposing the teachers, who already recognized the need to build analytical thinking capacity as observed through the off-line activities that they regularly introduce their students to, to the notions of serious games as well as visual programming and how these were to be used in classroom activities in the context of learning experiments.

Step 2, teacher training: demonstrations of the cMinds tools followed for building familiarity among the teachers on the actual use and functionality of the software to be deployed during the evaluation process.

Step 3, learner briefing: briefing of learners aimed at achieving their willing and motivated participation in the evaluation process. Briefing focused on the tools to be deployed for problem-solving. Scientific terms were avoided in this step. An overview demonstration of the functionality of the proposed serious game was part of the briefing process, which took place on the first day of the evaluation activities.

Step 4, deployment of the tutorial area: use of the tutorial area tools by learners for becoming familiar with the command toolset supported by the cMinds suite.

Step 5, solving puzzles through exploration, synthesis, and visualization: in this step learners were to be exposed to specific logical puzzles, use the exploration area for building insight on solutions, use the programming zone for synthesizing a program, and use the visualization capabilities for receiving feedback. This activity was to take place in small groups.

Step 6, documenting reactions and data collection: during the deployment of the tools learner and teacher reactions were to be documented for establishing perceptions, attitudes, motivation, and engagement. Thinking out loud processes were to be encouraged for facilitating the analytical thinking process and collaboration among team members. Where physical presence of the researcher is possible, data is documented in the form of images, videos, and text descriptions of activities taking place in the context of evaluation sessions during participatory observation. Where physical presence is not possible, i.e. when the learner groups are located abroad, data is collected through structured interviews/questionnaires.

Step 7, group collaboration, reflection, evaluation, and debriefing: group collaboration was planned to follow individual work in small teams. Group collaboration aimed at encouraging communication among all learners in the class: learners were to be asked to describe their solutions to the entire class for both establishing their level of understanding of their solution and explaining their solution step-by-step for the benefit of all. The optimization zone was to be further used during this step for further building in-depth knowledge on correct and optimal solution and for discussion potentially different approaches to addressing a specific problem. Additional activities such as drawing a solution or dramatizing could be used during this step could be optionally used by the teacher as a mediator.

A note on reflection and evaluation: the activities in this step integrate reflection by learners on their solution as well as evaluation of their solution, the solutions proposed by others, and the optimal solution. This activity is embedded in the wider learning experiment cycle and is of particular importance as it addresses one of the main criticisms of serious games which is the possibility that learners find the correct answer through random choices. Reflection and evaluation contribute to the elimination of this threat, which, however, is low in the case of this work as the synthesis of a viable program that solves a puzzle is very difficult to be achieved in a random manner.

Step 8, interviews with teachers: interviews with teachers upon completion of the evaluation activities were foreseen for establishing educator perceptions on the potential added value and learning benefits of the proposed serious games approach towards building analytical thinking capacity among learners.

Step 9, data analysis and review for drawing conclusions: this is the final step of the evaluation cycle during which conclusions are reached before a new cycle begins.

Notably the proposed evaluation cycle is close in-line with the proposition of Garris et al (2002) [71] on serious game deployment in learning contexts for ensuring knowledge increase.

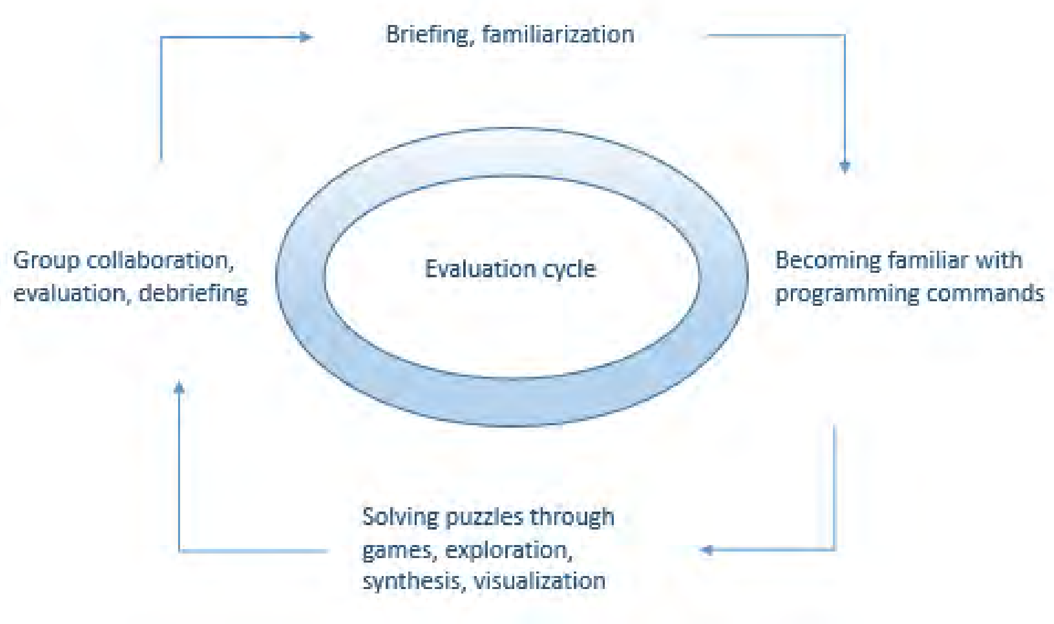


Figure 37. The evaluation cycle.

The number of participants in each country is summarized in the figure below.

Country	School	Age	# of girls	# of boys	Total participants
Greece	1st primary school of Volos	11-12	8	10	18
Greece	11th primary school of Volos	10-11	9	11	20
Czech Republic	6th ZS Kolin	9-10	9	12	21
Czech Republic	6th CS Kolin	11-12	8	9	17
Romania	Economic College Transylania	10	5	3	8
TOTAL					**84**

Figure 38. Summary of participants in evaluation activities.

The following sections provide an overview of the evaluation activities for establishing the potential added value of the cMinds learning suite as a serious game for promoting the development of early analytical thinking skills through programming.

3.5.7 Activities engaging 6th graders in the 1st primary school of Volos, GR

Activities in the 1st primary school of Volos engaged 6th graders in the spring of 2013. The class enrolled twenty students. Work was organized in collaboration with the informatics teacher of the school, Mr. Metafetzis. Learning experiments took place in the school computer lab, which is equipped with approximately ten computers installed next to each other in a line of adjacent desks.

In the session described below, students had already been briefed about the objectives of the activities, namely the deployment of software for building programs for solving logical puzzles. The students were already familiar with the functionality of the software, including the tutorial area, the structure of the supported visual commands, the exploration area, the robot zone, and the visualization capabilities. In fact, the students had already completed work on the deployment of the tutorial area, whose main learning objective is the familiarization with basic programming constructs that can be subsequently used for solving more complex puzzles. In addition, the students had successfully completed the Freezies activity that exposes users to pattern recognition and reproduction concepts.

The session focused on the deployment of the Eggs activity, which is a categorization exercise. It lasted 90 minutes. Students worked in six groups, four of which had three students and 2 of which had four students. The groups were chosen by the teacher aiming to integrate stronger and weaker students and to promote collaboration and transfer of knowledge from one student to another.

Figure 39. 1st primary school of Volos students synthesizing a solution to the Eggs puzzle in the programming zone.

Under teacher guidance, the groups were first encouraged to use the exploration area to develop insight on the solution of the puzzle. All groups were able to finish the activities, including all 5 levels. Notably, the lower levels of the puzzle require the use of only sequential commands as the learners are asked to sort only eggs of the same color. As the level of difficulty increases, the learners are asked to sort an increasing number of patterns. The solution of the higher levels of difficulty requires an understanding of conditionals and the use of either IF-THEN-ELSE statements or SWITCH as well as loops, namely the WHILE-DO command.

All groups were able to finish all five levels of difficulty of the suggested Egg activity. However, two groups were significantly faster, finishing in one hour, while the rest finished in one hour and twenty minutes. The groups finishing early demonstrated a confidence in the use of all programming structures and used the commands in the robot zone with apparent ease.

In relation to the remaining groups that faced higher challenges to complete all levels:

In one of the groups the students “cheated” without realizing it in the following way: they used the programming zone to program one step. Then they visualized the outcome in the visualization zone. Of course the program stopped without completing but this action gave them the opportunity to see the color of the next egg. This way they programmed step by step the solution without using a conditional statement as they knew the color of each coming egg. The students were then asked to produce a solution, i.e. program, which will work in all situations even when the colors of the forthcoming eggs are unknown. The students had difficulty understanding how a solution like the one requested might be produced. An explanation of the conditional statement, which allows checking the color of the next egg, proved very helpful. The students understood that the computer does not know how to do anything, so we have to state things very accurately and step-by-step. Once the students understood the functionality of the conditional statement they used it successfully to solve all 5 levels. A second group faced similar difficulties which were resolved after an overview of the structure of a conditional statement.

In another group the students had trouble understanding the exercise itself and what they were asked to do. This is an important element in analytical thinking processes. The students had difficulty restating the question that needed to be solved. They further had difficulty formulating the key question that would help them sort the egg. A small intervention was necessary. The students were asked what helps them decide which box to put each egg in. This corresponds to the condition / check of a conditional statement. The students understood that the key question to ask is on the color of the egg. Upon this they overcame the hurdle and completed all five difficulty levels of the exercise.

Notably, the exploration area in which students can experiment without programming for building intuition on potential solutions helped significantly in several ways: it allowed learners to build an understanding the given puzzle and it’s parameters; it allowed learners to repeatedly experiment until they understood the solution to the puzzle; and it introduced a game factor that encouraged engagement, in other words this part of the environment is similar to an arcade game.

All learners participated enthusiastically until the end of the session. They are eager to participate in future sessions with the other puzzles.

The students then moved on to the River Crossing puzzle. This puzzle has a different presentation between level one and the remaining levels. In level one the puzzle is presented in the form of helping a sheep, a wolf, and a cabbage cross a river with the restrictions that only two at a time can be in the boat and that two conflicting characters, that is, a pair in which the one would eat the other, like the wolf and the seep or the sheep and the cabbage, should not be left unattended on the same river bank. In levels two to five the puzzle is the same but is presented in a different manner: the students are asked to help transfer a group of soldiers from one bank of the river to the other with the help of two boys and a boat with the restriction that the boat can only hold one soldier or two boys or one soldier and one boy. The difference between level one and the remaining levels is the necessity to use a loop for solving the latter. The two strong teams solved level one very easily. This is probably due to the fact that they were already familiar with the specific representation of the exercise and they simply used the sequential commands of the tool to describe, or narrate, their solution. However, even the strong teams had trouble with level two, in which the input of the exercise is a group of soldiers, even though the solution is the same. This demonstrates a difficulty in transferring knowledge from one situation to another. However, the mistake the students introduced was not very significant: they simply had to remove one of the children from the boat upon reaching the opposite shore to make room for a soldier. By pointing this out the students were able to complete the exercise.

In another session, the same group of students worked in groups of three on seven computers. The session started by focusing on the Water Jugs puzzle. The puzzle asks learners to measure a requested volume of water by using three containers of given volume. They can fill the containers with water from a tap and can spill the entire contents of a container in a sink. The learners, already familiar with the tools by now, spontaneously turned to the exploration area for tackling level one of the puzzle. This puzzle is non-trivial and synthesizing a program for solving it is very difficult without first building a solid understanding of the solution off-line. Furthermore, the solutions are relatively long in terms of the required number of sequential commands.

Even in the exploration area, in which the students analyze the solution to a given problem, they had trouble solving level one, which asks users to measure 1lt of water given three containers of volume 7lt, 5lt, and 3lt. The source of the problem was lack of understanding that spilling the contents of a container is one of the supported actions. This is a result of insufficient understanding of the puzzle description as the capability of spilling is clearly stated. Once the students understood this point through teacher mediation they were able to solve level one of the puzzle in the exploration zone and moved on to synthesize a visual program that reproduces the solution in the programming zone. This they achieved step-by-step: they integrated a few commands, used the visualization to review the results, and continued in this process until the problem was solved. This was probably necessary due to the long solution. The learners used the programming zone as a means of taking notes and visualizing the results of their efforts.

Subsequently, learners moved on to level two of the exercise. This level asks learners to measure 4lt of water volume using two containers of 5lt and 3lt. The abstraction and complexity of the exercise instance in this level proved to be particularly challenging for learners. Even though they did solve the problem in the exploration zone they could not remember the solution as soon as they reached the “bravo” completion screen. They asked ‘ok how did we do that?’ This reflects a certain level of random exploration during the deployment of the exploration zone which leads to not remembering the actual steps following. However, this is not necessarily an unwanted scenario when viewed in the context of longer engagement with the tools. The students were encouraged to continue using the exploration zone for solving the problem until they reached a point where they could consciously reproduce the solution. Once they achieved that, they were also able to synthesize a program that described their solution in the robot zone using a step-by-step methodology of adding commands and visualizing the results similarly to the one they applied for solving level one. This demonstrates that it is necessary to build a complete understanding of a solution to a problem before describing it to someone else, in this case the computer, and is an indication of the positive effects on analytical skill building introduced by the proposed learning game. Different teams solved the problem in different ways that were also different from the solution presented in the optimization zone, which enabled a discussion an alternate approaches to tackling a problem and demonstrated individual thinking processes.

Next, learners moved on to level three of the exercise. The difficulty level became even more challenging for students, who were able to solve the puzzle in the exploration zone but had trouble remembering the long sequence of commands once attempting to synthesize a visual program in the programming zone. The teacher mentioned that in the past they overcame this difficulty by taking notes on paper. The exploration area proved to be of significant help at this stage as it was deployed by students during the programming phase as a means for remembering by acting the sequence of steps that needed to be programmed. Thus, the exploration zone in combination with the visualization capabilities and a step-by-step approach facilitated the successful completion of the visual program.

The above observations suggest that, as observed by researchers in the past, students are more likely to remember newly developed skills if they act on the specific knowledge [70], which is also one of the rationales for introducing active learning approaches through serious games for educational purposes. Other findings from this evaluation sequence include the fact that working in groups of two or three contributes very positively to thinking out loud processes leading the students to collaborative successful completion of exercises. Furthermore, the deployment of the visualization zone that animates the effects of a visual program as graphical, real-time feedback significantly contributes to the identification of faults in a program and their immediate correction, demonstrating that feedback gaming mechanisms offer learning benefits in terms of knowledge scaffolding.

The next exercise that the students worked on was the Santa Claus exercise. The story line of the exercise involves a forgetful Santa who accidentally puts his dirty socks into a gift package. The students are asked to find the package, which is heavier as a result of containing the socks in addition to the gift, by weighing the otherwise identical packages.

Figure 40. 1st primary school students working on the water jugs exercise.

This exercise has two solutions: The straightforward, yet non-optimal, solution approach involves weighting packages in pairs until the heaviest package is located. The more efficient approach deploys a divide-and-conquer technique in which half of the packages are weighed against the other half and this process is continued with the heavier lot until only one package is left.

Despite the fact that this was considered to be a more difficult exercise due to the advanced algorithmic nature of the divide and conquer technique students solved the puzzle with relative ease. In addition, the students used the divide and conquer method directly without first trying the seemingly more straightforward brute force solution.

3.5.8 Activities engaging 5th graders in the 11th primary school of Volos, GR

Activities engaging learners at the 11th primary school of Volos took place in the spring of 2013. A group of 18 5th graders was engaged in the activities. Learners had no programming experience; informatics courses involve only the use of tools such as word processors and web browsers. Learners worked in the school computer laboratory in groups of three. In contrast with the work that took place at the 1st primary school of Volos, the small teams of three were seated in a round table. As students worked in a cycle, this arrangement created an additional team which consisted of the entire class and promoted collaboration of the entire group as a whole in addition to the work that took place among the small teams. Furthermore, the teacher took a more active role as a mediator directing questions in the context of collaboration on problem solving among members of the whole class, which took place after learners had the opportunity to work on a given problem within their small, three member groups. Notably, students had already worked on the cMinds suite in the fall 2012 semester. Work at that time took place in the context of the free zone of the school curricula, which allows teachers to introduce learners in a flexible manner to extra curricula topics that add value to school activities.

Students first used the River Crossing activity, and specifically levels one to three. One student read out loud the objective of the exercise for the benefit of the entire class, thus facilitating group work and building a team spirit among all class members. Under teacher mediation, all learners in the class participated in a collaborative discussion during which they stated out loud the given puzzle parameters; they further described what they were asked to achieve in a precise manner, namely helping a very specific group, which differed based on the difficulty level of the exercise, to cross the river taking into account specific rules. This discussion is part of the analytical thinking process and helped learners build a deeper understanding of the restrictions imposed by the puzzle as, for example, that in level one the wolf and the sheep are not allowed to be left unattended together on the same river bank. Once the students understood the restrictions for level one, they were able to solve the puzzle in the exploration area with relative ease and moved on to synthesizing a program for solving the puzzle in the programming zone. Group work in teams of three was very beneficial as it actively promoted a thinking out loud process.

Four out of the six groups solved level one in the programming zone and moved on to levels two and three. Notably, the solution to levels two and three is exactly the same. The only difference between the two levels is the number of soldiers than need to cross the river. However, and given the fact that an iterative, loop process can be used as a solution to the exercise, the increase of the number of soldiers that need to cross the river does not require a different solution between levels two and three. The same solution can work in both cases. What is different is the fact that in level two the number of soldiers that learners must help cross the river is only four, which led some of the groups to solve the puzzle using only sequential commands, as opposed to a loop.

Notably, when learners had difficulties remembering the next step to follow during program synthesis they used the exploration area to refresh the solution in their memory. This, similarly to what was observed with learners in the 1st primary school, demonstrates the fact that free exploration and programming offer a good combination that can contribute positively to building problem solving skills.

Another interesting observation is related to the use of the optimization area in which an optimal solution with a minimum number of steps is hard coded. The risk of this design choice is that learners can use the area as a cheat sheet for seeing upcoming programming steps thus avoiding thinking analytically for themselves. Interestingly, only one group acted in this manner. The other five groups used the software in the foreseen manner by alternating between the exploration and programming zones for making progress in their problem solving efforts.

In relation to the gamification elements of the programming suite, the simple “bravo” screen acted as a significant motivator and was a source of pride offering learners a sense of achievement. Some learners stubbornly continued to work and refused to stop before reaching the “bravo” screen. This demonstrates that even simple gamification principles can have a positive impact on engagement with higher thinking processes.

After the work in small groups was completed the class convened to a collaboration session that involved all students becoming a single group of 18 participants. During this process learners were asked to describe loud for the benefit of their peers their solution. Describing the solution for the benefit of the group had multiple learning advantages. First, learners had a sense of significant pride and achievement in helping others understand the solution. Second, it allowed the groups that had not reached completion of the exercise to reflect on and understand the correct solution. And finally, it allowed learners to compare solutions thus building a deeper understanding of the fact that alternative implementation paths do exist to a given problem. The optimization zone was used by the entire group at this stage to review a solution with a minimum number of implementation steps. This was particularly useful in difficulty level two of the exercise in which some of the groups selected sequential solutions. With the optimization zone the students were able to see the benefits of a solution based on a loop in terms of reducing the size of the visual code but still achieving the desired result.

Learners in the 5th grade did have some difficulties applying the loop structure, which was necessary in level three of the exercise due to the large number of soldiers needing to cross the river. As a reminder, 6th graders did not face difficulties using the loop structure. However, 5th graders were able to describe loud how the loop structure works which means that they did gain an understanding of how programming structures work.

In a follow up session, the same group of learners focused on the Egg Sorting exercise. They worked in groups of two or three on nine computers. Similarly to the work described earlier in this section, one student read out loud for the benefit of the group the exercise objectives. Subsequently, the students participated in a collaborative session during which the teacher asked directed questions with the objective of helping students understand what they are asked to achieve and what are the rules and restrictions imposed. For level one of the exercise, which involves eggs of a single color that must be stored in one of several available boxes using as a criterion the decoration pattern, which must be matching on the eggs and the box, the questions were of the type ‘how many eggs do we have?’ and ‘which box should the eggs go into?'. For level difficulty two, which involves eggs of two different colors, the questions were of the type 'how many eggs do we have?', 'of what color?', and 'which boxes should the eggs go into?'.

The students used directly the programming zone for solving the puzzle. This is due to the fact that, analytically, they already had a good idea of how to solve the puzzle and thus they did not need to use the exploration zone for building insight on a potential solution. For level difficulty one most groups used only sequential commands during program synthesis. This is possibly a reasonable approach when only one type of eggs is input to the puzzle and the number of input eggs is small.

For level difficulty two the puzzle can no longer be solved sequentially because two types of eggs are given as input to the puzzle; the color of each egg needs to be checked for deciding which box the egg should go into. At this stage some groups initially synthesized a visual program step-by-step using the visualization tool of the suite in order to review the effects of their partial solution but also in order to see the color of the next egg in the sequence, which allowed them to avoid using a conditional. This is not a desirable approach and it was explained to the learners that they need to construct a solution keeping in mind that they do not know the color of the next egg. In other words, they need to synthesize a program that solves the puzzle independently of the sequence of eggs; the program will tell the computer how to sort the eggs without knowing the color beforehand. Once this was explained the groups started using the while command in order to build a loop that processes all eggs. However, even at this stage the learners did not use a conditional statement for checking the color of the egg; rather they used a solution of the form:

```
WHILE there are still eggs on the table
DO
        put in the green box;
        put in the red box;
        put in the blue box;
```

This sequence actually works even if a conditional statement is not used because the suite does nothing if the egg does not match the box thus attempting the next box in the row of boxes.

The analytical difficulty faced by the learners was the fact that they did not understand the concept of “nesting”, namely that they are allowed to include a conditional statement within a loop statement. Once it was explained to them that this is allowed, learners were able to solve the puzzle in the programming zone. Notably, 6th graders did not face challenges understanding this level of abstraction.

Upon completion of the work in small groups a learner described the solution loud for the benefit of the entire class.

Figure 41. Learners at the 11th primary school of Volos working on the eggs activity.

Next, the learners were asked to work on the Water Jugs activity. Learners first addressed difficulty level one. One learner read out loud the objective of the exercise and then the group repeated. Learners understood that this was considered to be a difficult exercise for them. This provided motivation; the learners said that they loved the challenge. Surprisingly, learners went up to levels three or four within twenty minutes. They solved the exercise in the exploration area as well as in the programming zone. Similarly to what they did in other puzzles, learners alternated between the exploration and programming areas when they needed some help for remembering the next step in synthesizing a solution.

The relative ease with which learners solved the Water Jugs puzzle may be related to the fact that they had been using the cMinds suite for an entire semester in the fall of 2012. This is an indication that the deployment of the tools did contribute to the development of analytical thinking pathways as learners performed significantly better than their older counterparts in the 1st primary school of Volos on the Water Jugs puzzle.

The teacher commented that the deployment of recreational games after school did not help learners build problem solving skills. Rather, the activities that took place during the evaluation session were more related to work taking place in the context of mathematics at school. Math and science work, combined with the deployment of the tools, helped learners build analytical capacity. The teacher further commented that the gamification process continues after the end of the class. A competitive spirit is evident in student discussions that continue over recess and throughout the school day. For this reason, weekly use of the tools is very constructive as it allows learners to think about potential solutions at home and apply the solutions in the next session.

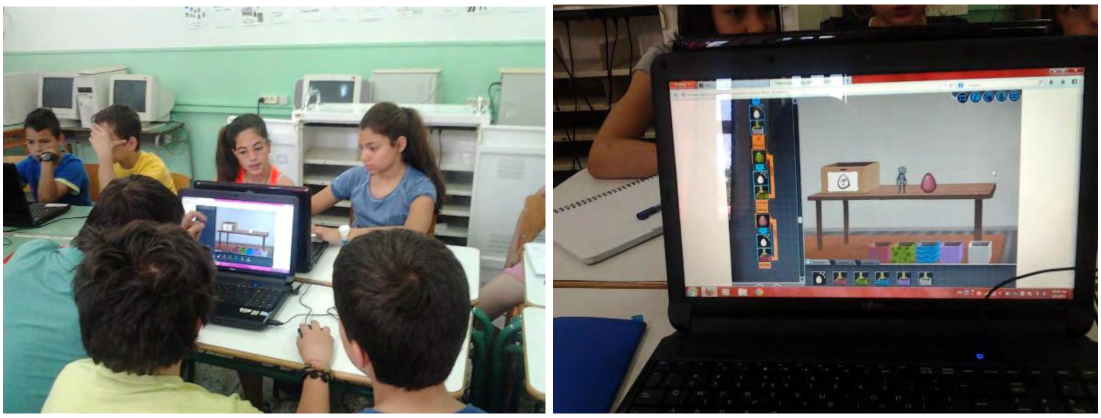


Figure 42. Learners at the 11th primary school of Volos working collaboratively in a round table.

3.5.9 Evaluation activities at 6ZS Kolin, CZ

Activities at 6ZS Kolin took place in the spring and fall of 2012 for a total period of six months. Learners, under the guidance of their teachers worked with most of the puzzles in 45 minute sessions that were repeated throughout the fall semester.

The learners first became familiar with the general objectives and functionality of the cMinds suite towards the development of analytical and critical thinking skills. The learners were exposed to the tutorial area for building an understanding of the function of basic programming constructs. The learners subsequently worked on the lab computers. The work was individual. The students worked with all the logical puzzles available in the programming environment. Similarly to what happened in one of the Greek schools the teacher first encouraged learners to think analytically on a potential solution to a given puzzle before using the programming zone to synthesize a program that solves the problem at hand. Most students followed the teacher methodology. Some initially tried to drag and drop commands randomly in the programming zone to try to get the robot to solve the given exercise. This approach of course did not lead to success. Gradually students understood the importance of first solving the solution analytically, using experience built by working in the semi-structured exploration area, before attempting the synthesis of a visual program. This was a result that pleased the teachers and demonstrated that an environment that encourages the development of a strategy for analyzing a solution to a problem through exploration and subsequently through synthesis can promote problem solving mindsets.

Upon completion of the individual work, the teachers, sometimes in a follow-up session, asked a student to solve the problem on a whiteboard with the entire class participating when necessary for making progress towards building a complete program. This classroom collaboration helped learners scaffold knowledge and build a deeper understanding of their solution by describing it to others. This is demonstrated below in Figure 43 (right) which shows a student working on a digital whiteboard while the class (not pictured) participates for helping shape a solution.

Figure 43. Learners at ZS Kolin practicing with the tutorial area of cMinds; individual work (left) and follow-up class collaboration (right).

One issue that came up was why it is important to introduce an optimal solution. For example, in the math activity in which students are encouraged to perform a subtraction by jumping to the closest multiple of 10 and then using multiples of 10 to reach the target students asked why it is important to achieve a solution with the minimum number of steps. The teacher made a comparison with energy saving solutions thus linking a math activity to other science subjects. The teacher pointed out that fewer steps usually means fewer expenses. As the teacher, Hana, commented, ‘the math activity helped the children understand mathematics concepts such as addition, subtraction, and approximation; the students also understood why it is important to compose good and smart solutions’. Learners successfully finished the tutorial area, the Santa Claus activity, the river crossing activity, the math activity, and the Freezies activity. Some learners had trouble with the water jugs activity. They had issues imagining a solution before starting the programming process. In addition to using the exploration area for building intuition on potential solutions learners also sketched solutions on paper under teacher guidance and encouragement.

In relation to rewards, the students were particularly interested in reaching the “bravo” screen. Students were further particularly eager to share their findings with the class in collaborative sessions that fostered peer learning. The teacher commented that the activity was very beneficial to the class since ‘children did not use the computer as a communication tool; rather, they discovered the logic and system activities through a special type of game that is close to their need of fun’.

The teacher conducted interviews with the learners based on a specific questionnaire which appears in Appendix I. 21 students aged 9-10 years participated in the interviews out of which 9 were girls and 12 were boys. The learners’ responses are summarized below.

Learners responded that they have never been exposed to programming before. When asked if programming concepts were difficult to understand through the gaming environment learners responded that they were not. Teacher intervention for explaining some concepts was, however, useful for some students. When asked if they feel that they can engage in programming after being exposed to the cMinds serious game learners replied either ‘yes’ or ‘a little’. Only boys replied that they can use programming ‘a little’. Learners felt that programming helped them solve tasks and make decisions. What they liked mostly about the learning process was the feeling of success and the fact that they ‘had to think’. In relation to specific learning activities that learners mostly enjoyed the answers evenly divided among the Santa Claus, River Crossing, tutorial, and Freezies puzzles. In addition, learners liked the user interface graphics. Learners commented that engagement with the hands-on, semi-structured exploration area helped them understand potential solutions in preparation for building a visual program. 95% of the learners commented that they would use the software again. 95% commented that they felt that a tool like the one proposed would make mathematics and science educational activities more attractive. In relation to whether they preferred individual or collaborative work learners were equally divided. The following figure summarizes the responses of learners.

ZS Kolin learners 9-10	Number (#)		Percent (%)
# of students with prior exposure to programming	0		0
# of students who replied that they can use programming "yes" or "a little"	21		100
# of students who replied that programming helped in problem solving	21		100
	yes	no	Percent (%)
Was programming easier after seeing the animated feedback?	15	5	71
Will you use the software again?	19	2	95
Does this method make math and science more attractive?	20	1	95
Do you feel more confident in problem solving now?	21	0	100
Was the software attractive?	20	1	95
	individually	collaboratively	
What is your preferred method of work	11	10	

Figure 44. Evaluation results in the Czech Republic among learners aged 9-10 years.

The same questionnaire was replied to by a group of 17 learners aged 11-12 years out of whom 8 were girls and 9 were boys. The responses are summarized below.

10 of the learners said that they had been exposed to the notion of programming through ICT courses. 88% of the learners responded that programming was not difficult to understand or that it was a little difficult to understand at the beginning. 2 learners responded that programming was difficult to understand. When asked if they feel that they can use programming now 82% of learners responded ‘yes’ and only 3 learners responded ‘a little’ or ‘no’. In relation to the activity that was most interesting 6 learners were more attracted to the river crossing puzzle while the rest were evenly divided between the remaining activities. When asked if the software was attractive 94% of the students made positive comments and 1 replied ‘no’. The students described the software as ‘very attractive’, ‘attractive’, ‘funny’, and ‘interesting’. All 94% of learners responded that it was easier to solve a problem after engaging in the semi-structured exploration area; 1 student responded that the difficulty was the same before and after engaging in the exploration area. 6 learners finished the river crossing activity, 4 the math activity, 7 the pattern matching egg decoration activity, 1 all activities, and 1 ‘just some’ activities. 94% of the learners responded that they at least ‘likely’ have improved their problem solving skills; 1 responded ‘probably not’. 94% of learners responded that they would use the software again; 1 responded ‘probably

not' and 2 responded 'maybe'. When asked if the tool can make mathematics and science education more attractive 64% of learners responded positively; 2 responded 'I don't know' and 4 responded 'no'. Learners unanimously commented that they prefer collaborative work. Finally, in relation to what they would recommend for improving the tool learners 50% of learners replied that they liked it as it is, 1 responded that the graphics could improve, 1 proposed more tasks, 1 proposed different age categories, 1 proposed more exact explanations, 1 proposed more clues, and 1 proposed more difficulty levels. The following figure summarizes the responses of learners.

ZS Kolin learners 11-12	Number (#)		Percent (%)
# of students with prior exposure to programming	10		59
# of students who replied that programming helped with problem solving	17		100
# of students who replied that they can use programming "yes" or "a little"	17		100
	yes	**no**	**Percent (%)**
Was programming easier after seeing the animated feedback?	17	0	100
Will you use the software again?	16	1	94
Does this method make math and science more attractive?	11	4	64
Was the software attractive?	16	1	94
Did the hands-on area help in problem solving	16	1	94
	individually	**collaboratively**	
What is your preferred method of work	4	17	

Figure 45. Evaluation results in the Czech Republic among learners aged 11-12 years.

3.5.10 Evaluation activities at CETTM Targu Mures, RO

Evaluation activities in Romania took place at the CETTM Targu Mures primary and lower secondary school. The activities took place in the spring and fall of 2012 for a total period of six months.

The school does not possess a computer laboratory. In an introductory phase, learners initially were introduced to the cMinds learning suite through a presentation on a digital whiteboard that took place in the classroom. Subsequently, in a practical engagement phase, learners worked on the activities on a single computer. This setup was necessary given the lack of further equipment. Learners worked on the activities either individually or in groups of two. The activities took place in the context of mathematics courses and complemented existing practices towards building problem solving and analytical thinking capacity. The time allocated was approximately two hours per week.

Figure 46. Learners working with the cMinds suite at CETTM Targu Mures school: introductory presentation on a digital whiteboard (left); working on the tutorial area (right).

During engagement students were encouraged to exchange ideas before individually synthesizing a solution. This process was facilitated by the class teacher who encouraged learners to engage in problem solving methodologies with wide applications.

The learners were exposed to all of the logical puzzles that are available through the cMinds learning environment. When engaging in a particular puzzle, learners initially worked in the exploration area for building a basic understanding of an approach towards building a solution. Subsequently, learners worked in the programming zone for synthesizing a visual program. The process was repeated in a circular manner until learners were able to consistently reproduce a correct solution via programming.

The mathematics activity provided a good opportunity for learners to understand the utility of the while-loop towards building a solution that is not only correct but also efficient. The activity gave the opportunity to learners to understand the concept of termination conditions in while-loops. The Freezies activity was familiar to learners as they already work on pattern recognition in the context of mathematics. Similarly, the eggs activity proved to be relatively easy to tackle and was attractive to learners as a result of the related graphics. During the Santa Claus activity learners were able to build a brute force program in which two packages are weighted at a time for finding the heavier one in pile. They needed teacher guidance to understand the more advanced divide-and-conquer technique in which half of the packages are weighed against the other half. With teacher guidance they were able to synthesize a divide-and-conquer solution and to understand that it is more efficient due to the lesser number of implementation steps that it requires.

Teachers commented that ‘the cMinds suite can be easily integrated into mathematics and ICT lessons but with some imagination on behalf of the teacher it can also be integrated into science’. They also commented that ‘learners’ collaboration resulted in new solutions and valid observations’ pointing to the usefulness of a collaborative class organization for maximizing impact.

Towards the end of the evaluation activities the teachers conducted interviews with 8 of the students based on the questionnaire that appears on Appendix I. The students that were interviewed were 10 years old. 5 of them were girls and 3 were boys. The responses are summarized below.

Learners replied that they were not familiar with programming. The exception was one learner whose uncle was a programmer and thus had been exposed to ICT outside of school in his family environment. Learners responded that they had difficulty engaging in programming activities only in the beginning of the process. In relation to whether programming helped them organize their thoughts for solving a problem, learners responded that it did. What was particularly useful was the fact that it guided them to think ahead on implementation steps and to understand that they need to build a solution systematically and not through random choices.

In relation to how they used the tools the learners commented that they used all aspects of the tools. They used the memo zone for taking notes. They used the comparison zone for reviewing an optimal solution and understand how it differs from their own. They used the animation for getting feedback on the effects of their visual programs under construction. They further liked the variety of the puzzles and the problem solving process itself. All learners found the software attractive. They further liked the gaming approach to programming and specifically the challenge it introduced. The most interesting feedback was the animation of the program as stated in replies to other questions as well. The exploration area helped them organize their thoughts as it provided a different view on the puzzle at hand and contributed to an easier introduction to visual programming in a subsequent step. 75% of the learners completed all exercises with only 2 stating that they did not complete the river crossing puzzle. Learners responded that they feel more confident in problem solving after being engaged in the analytical thinking processes through cMinds. Finally, in relation to which aspect of the learning process they liked the most 50% responded that they liked the Santa Claus exercise while the rest were evenly divided between the water jugs, decorated eggs, and river crossing puzzles. 87% of the students responded that they would use the software again with only 1 responding ‘maybe’. All learners responded that they believed that such tools make mathematics and science education more attractive. In relation to what they would suggest as an improvement all learners proposed the introduction of additional puzzles; one suggested 3D graphics. Finally, in relation to weather they preferred working individually or in groups 87% learners preferred collaborative work; one responded that he would prefer individual work followed by a collaborative session for comparison of results. Following is a summary of learner responses.

CETTM learners aged 10	**Number (#)**		**Percent(%)**
# of students with prior exposure to programming	7		88
# of students who replied that programming helped with problem solving	8		100
# of students who replied that they can use programming "yes" or "a little"	8		100
# of students that finished all exercises	6		75
	yes	**no**	**Percent (%)**
Was programming easier after seeing the animated feedback?	8	0	100
Will you use the software again?	7	1	88
Does this method make math and science more attractive?	8	0	100
Was the software attractive?	8	0	100
Do you feel more confident in problem solving now?	8	0	100
	individually	**collaboratively**	
What is your preferred method of work	1	7	

Figure 47. Evaluation results in Romania among learners aged 10 years.

The following figure presents a side by side summary of results in the Czech Republic and Romania. The results are comparable with the exception of how the proposed methodology can make math and science more attractive. To this question the older learners from the Czech Republic provided responses that showed a desire for more challenge.

	Romania	Czech Republic
Comparison	**Percent (#)**	**Percent (#)**
# of students with prior exposure to programming	88	82
# of students who replied that they can use programming "yes" or "a little"	100	100
# of students who replied that programming helped in problem solving	100	100
	Percent yes (%)	**Percent yes (#)**
Was programming easier after seeing the animated feedback?	**100**	**84**
Will you use the software again?	88	92
Does this method make math and science more attractive?	100	86
Was the software attractive?	100	95
Do you feel more confident in problem solving now?	100	100
	Percent collaborative (%)	**Percent collaborative (%)**
What is your preferred method of work?	88	71

Figure 48. Comparison of summary evaluation results in Romania and the Czech Republic.

3.6 Analysis of evaluation findings

This section introduces a discussion on evaluation findings from the deployment of the cMinds suite in schools in Greece, the Czech Republic, and Romania.

3.6.1 Contribution of gamification elements to engagement in learning processes towards analytical thinking capacity building

Does gamification of programming through elements such as recognition of achievement, difficulty levels, and medals positively influence engagement in learning processes towards building analytical thinking capacity and problem solving skills?

The activities demonstrated that gaming elements were highly motivational for the longer engagement of learners with problem solving activities.

The “bravo” screen corresponds to an achievement reward that learners receive upon the successful completion of a single level of difficulty of a particular exercise. Learners see this screen in two different instances of their engagement with the cMinds programming environment: upon discovering a solution via semi-structured experimentation in the exploration phase during which they build insight on potential solutions to a given puzzle; and after successfully synthesizing a visual program in the programming zone.

The “bravo” screen had a very positive influence on learners providing a sense of achievement and pride and encouraging further engagement of the learner with analytical thinking processes in higher difficulty levels of a specific exercise. Notably, all learners reacted positively to the reward of the “bravo” screen. Characteristically, some learners were very persistent in their efforts and unwilling to quit an exercise before successfully completing it leading to a “bravo” screen. Typically, these learners were the more competitive ones that reacted positively to the other gamification elements of the cMinds visual programming environment.

Subsequently, higher levels of difficulty of a given exercise further promoted the engagement of learners with analytical thinking processes. In higher difficulty levels the objective of an exercise remains the same. The input parameters change with the objective of exposing learners to richer challenges. As such, this gamification element does not introduce novelty in terms of a different exercise; rather, it encourages learners to exploit the knowledge built through the solution of lower difficulty levels and to apply this knowledge in similar but more difficult instances of the same exercise. The increasing levels of difficulty prolong the engagement with a specific exercise designed for building analytical thinking capacity, introduce a degree of repletion and transfer of knowledge to similar yet more difficult exercises thus promoting knowledge scaffolding, and promotes a sense of achievement among learners in the form of progress towards reaching the final goal of solving all levels of difficulty.

The “star” medal reward that learners gain upon completion of all five levels of difficulty acted as a motivational element for encouraging learners to complete the entire game. It corresponds to a multiple level achievement reward. Typically, 30% of the participant learners completed all five levels of difficulty. The “star” reward introduced an element of surprise for learners as it was not explicitly described to learners at the beginning of their engagement with problem solving through cMinds. It introduced a level of competition as additional teams strived for solving all five difficulty levels of a given exercise aiming at receiving a “star” medal.

In conclusion, gamification elements had a positive influence in encouraging learners to engage with problem solving processes. Gaming elements in the form of single-level achievement rewards, difficulty levels, and multiple-level achievement rewards enhanced engagement levels and motivation to participating in higher order thinking activities. Gaming elements introduced concrete goals that learners could only reach through targeted effort and engagement. Gamification further fostered a spirit of competition with oneself and with peers, further promoting engagement with learning processes and adding value in learning experiences related to problem solving.

3.6.2 Contribution of game-based exploration towards building analytical thinking capacity

Does game-based exploration help learners build intuition on potential solutions to logical puzzles?

Before engaging in the synthesis of a precise solution via visual programming learners are exposed to a semi-structured exploration process in a dedicated area of the cMinds learning suite through which they are encouraged to build intuition on viable, if not optimal, solutions by dragging and dropping elements that can be used as resources towards solving a specific puzzle. Exploration and experimentation activities contributed significantly in learner engagement and successful execution of an exercise in several ways. They added value to the learning process in several ways. They allowed the development by learners of a clear understanding of problem objectives, input parameters, and rules related to the solution of the given exercise. They contributed to building an initial understanding of a potential correct solution. They introduced a gaming element that was highly motivational for learners particularly in early engagement stages with non-trivial puzzles; exploration and experimentation activities eased learners into higher order thinking processes helping them to build self-confidence for tackling a given exercise through the more challenging exercise of visual programming.

The exploration area may be perceived to resemble arcade games designed for entertainment purposes. Learners may have been exposed to similar exercise through emerging gaming tablets that support educational games. The exploration area provides an interim learning step that may help learners to not feel intimidated by the programming activity.

In addition, the exploration area provides a helpful reference point to which learners can resort in an iterative manner when facing difficulties during programming. In such circumstances, the exploration zone acts as a tool that allows learners to either refresh their memory on a solution that they have already achieved by manipulating resources with a mouse, i.e. dragging and dropping, but have trouble synthesizing in the form of a visual program. The exploration area allows learners to repeat the execution of a solution thus building a thorough understanding of the solution implementation steps. Learners used this area in an iterative manner during programming for step-wise adding visual commands to a non-trivial program. For many learners, the semi-structured exploration replaced the process of taking notes on paper for remembering a given sequence of programming commands. The exploration was superior to taking notes due to the visual representation of a solution that contributed to understanding mistakes through a cause and effect mechanism and for trying out potential implementation paths until a working solution was reached.

In conclusion, the arcade gaming element of semi-structured exploration provided significant motivation in the early stages of engagement with analytical thinking processes. It further helped longer-term learner engagement with higher order thinking processes by providing an alternative implementation tool to which learners could resort in case of difficulty. While learners perceived this process as a game, the process in fact actively contributed towards the development of a conscious understanding of potential solutions. Combined with the visual programming activity, the semi-structured exploration appeared to be a strong tool for promoting engagement and helping learners engage with analytical thinking processes such as recognizing the learning objective of an exercise, identifying input parameters, identifying resources available for solving the exercise at hand, understanding imposed rules, and step-wise reproducing a solution through, if necessary, repetition of steps in the context of a perceived game.

3.6.3 Contribution of game-based programming towards problem solving and solution synthesis capacity building

Does game-based programming as a synthesis tool help learners accurately understand and precisely reproduce a solution to a logical puzzle and explain it to others?

Upon successfully solving a problem in the exploration area learners were asked to synthesize a solution that solves the problem automatically through the programming zone. Interestingly, learners perceived the visual coding activity itself as a game. They did not have a feeling of being engaged in programming and the word programming did not arise in communication among learners and learner-teacher discussions during learner engagement with learning activities. Learners were immersed in the problem solving process of accurately explaining to another, in this case the computer, in a precise manner through a series of visual commands how their solution can be implemented and reproduced step by step. This indicates that educational design in which programming is approached as a learning game may introduce learners at an early age to advanced cognitive activities such as synthesis in a playful manner. It may ease learners into analytical thinking activities in the context of programming curricula with which they would otherwise be engaged optionally in a much later stage of their educational path in K12 such as upper secondary school.

This was further evident during the engagement of learners with logical puzzles with non-trivial solutions. One such activity was a classic divide-and-conquer exercise in the form of the Santa Claus dirty socks puzzle described above. In the context of this evaluation learners immediately chose the optimal divide-and-conquer solution of the puzzle over the brute force solution, which is correct but sub-optimal. This demonstrates that learners have the capacity to apply non-trivial thinking patterns when exposed to a complex puzzle in a playful manner in the correct context. Serious games can be used for introducing learners to concepts and algorithms, such as divide-and-conquer, to which they would otherwise be introduced much later, possibly in the first year of higher education studies in ICT.

Figure 49. Visual hints in the Santa Claus exercise provided context and helped learners identify the optimal divide-and-conquer solution.

The programming zone provided a clear opportunity for evaluating whether learners can analytically synthesize a solution to a given puzzle through visual programming. This is the case because the programming area minimizes the possibility of random choices used by learners until a solution is accidentally found. Rather, programming is a precise activity that promotes structured thinking mindsets.

The evaluation activities highlighted the fact that both 5th and 6th graders had the capacity to solve all logical puzzles they were exposed to, although some hints needed to be provided to some of the groups to help them advance. As might be expected, older learners had higher capacity in understanding and applying in practice abstraction principles. More precisely, one differentiating factor in terms of exercise completion capacity was that 6th graders easier grasped the concept of nesting, in other words the fact that a loop can be inserted inside a conditional statement. 5th graders needed concrete explanation of this concept after which they solved the puzzles with no further problems.

In conclusion, educational games can enhance learning experiences exposing learners to rich blended educational activities when combined with formal instruction in the context of broader, blended learning design. Programming games were deployed during the flexible zone of curriculum in which teachers are encouraged to introduce educational activities that are complementary to the school's formal educational program.

3.6.4 Significance of the integration of programming games into wider learning processes; direction and class collaboration

Does class collaboration and teacher mediation positively influence analytical thinking skill development through game-based learning design that deploys programming?

The most interesting observation is related to the importance of the organization of the work in the classroom towards building analytical thinking capacity through games. In other words, the method used for integrating serious games into learning activities is significant for the achievement of learning objectives.

During the evaluation activities learners in both schools worked in small groups in the school computer lab. The groups involved two to three students. However, there were some differences in work organization. The groups in the 1st primary school of Volos, Greece worked largely independently with little collaboration among them. Teacher mediation was limited allowing learners to freely explore the game and providing direction mostly on software functionality.

On the other hand, learners in the 11th primary school of Volos worked in similarly small groups of two to three which, however, were seated in a round-table setting promoting further collaboration among the teams. Teacher mediation was higher especially during the description of the puzzle that took place at the beginning of engagement with a specific exercise and during the debriefing and explanation of a viable solution that took place at the end of the activity for promoting knowledge scaffolding and retention. During these two phases the entire class worked collaborative in a large group. The round table organization of the seats in the computer lab contributed positively to the development of a collaborative spirit and, to a certain extent, a competition spirit among teams.

Learners at 6ZS Kolin worked in pairs or small groups. This work was followed by collaborative class de-briefing. In Romania learners started the work in a class-wide collaboration session, subsequently worked individually, and close the activities through collaborative class de-briefing.

During the puzzle introduction phase the teacher introduced directive questions that helped learners understand input parameters, restrictions, rules, and objectives of a given puzzle. Learners were invited to respond, and the teacher documented the responses on the blackboard for the benefit of the entire class. Learners participated in this process with great enthusiasm. They were eager to demonstrate to the group their understanding of a problem and the opportunity they were provided to steer their classmates to the right direction for solving the puzzle introduced a sense of achievement, pride, and satisfaction.

Figure 50. 6th grade learners working on the sorting puzzle at the 1st primary school of Volos in small independent groups (left); 5th grade learners working on the volume measurement puzzle at the 11th primary school of Volos in small groups seated in a round table (right).

During the de-briefing and collaboration phase that took place after learners worked in their teams on synthesizing the solution to a given puzzle learners were encouraged to present in words to their peers their solution to the exercise. The teacher documented again the steps on the blackboard for the benefit of the entire class. This narrative approach had several advantages. First, it provided an additional opportunity to explain the solution to others, this time the members of the class. This complemented the digital narration in the form of precise programming commands that learners were engaged with in the programming phase. It ensured additionally the fact that learners had a thorough understanding of the solution they suggested and that the solution was not achieved through random experimentation. On the other hand, during this phase several correct solutions were presented allowing learners to compare implementation paths and understand the concept of optimality and cost reduction.

Notably, the gaming process for solving analytically logical puzzles through exploration and visual programming itself does provide a significant degree of direction. Exploration is semi-structured. During exploration learners can only work with specific resources available on the screen. While learners can at this stage make random selections, the fact that they can only engage with the necessary elements for solving a problem and not others provides direction and hints towards a possible solution. The inherent degree of randomness in this process which stems from the fact that learners can click on objects on the screen without necessarily having a clear idea of how to solve a problem is not necessarily undesirable. The objective of the exploration area is to allow learners to experiment, even randomly in the beginning of the learning process, until they build an understanding of a potential solution approach. In later stages of engagement learners use the exploration zone consciously for reproducing consistently the desirable solution before engaging in programming activities. On the other hand, the visual programming zone provides a degree of direction by presenting learners with visual commands that are directly related to the problem at hand. The optimization zone, which demonstrates the solution with the minimum number of implementation steps, acts as a further degree of direction for learners towards reaching a viable solution.

Summarizing, direction towards learners in the context of learning activities is provided in two ways:

- Through the programming game design that provides direction through semi-structured exploration, visual presentations of relevant commands, and presentation of the optimal solution
- Through the integration of programming gaming activities into wider classroom collaboration

The evaluation showed that the organization of the work in a round-table, as practiced by the 5th grade class in the 11th primary school, with some direction by teachers helped learners achieve higher success than the organization in individual groups with lower collaboration between them. This finding is in line with work by Kirshner and al. [136] that discusses the need for direction in building analytical thinking skills. The round-table organization and discussion among all class members contributed to a better understanding of a given puzzle's objectives, clearer identification of smaller problems hidden within the puzzle whose solution could lead to an overall synthesized solution, and better understanding of the final solution. Class collaboration led to higher overall performance of the class despite their younger age as compared to the other group. This shows that effectiveness of the deployment of games in learning is highly related to the broader learning activities in which games are integrated, to debriefing, and to discussion and collaboration.

In conclusion, the evaluation processes demonstrated that the organization of the classroom and class collaboration contributed to analytical thinking skill development through serious games through collective activities that allowed learners to build on each other's knowledge and skills promoting higher completion rates of exercises and higher engagement in the learning process. Teacher direction and mediation positively affected the scaffolding of knowledge through targeted questions that eased learners through the analytical thinking process by enabling them to understand as a group project objectives, input parameters, resources, and viable solutions. Direction embedded into the programming game provided hints that helped learners build an understanding of potential solutions through semi-structured exploration, relevant command toolsets, and demonstration of optimal solutions.

3.6.5 Limitations of the work

The evaluation approach followed in the schools in Greece an in the school in the Czech Republic and Romania varied as in Greece work involved participatory observation while the work in Romania and the Czech Republic was documented through interviews with the learners. In addition, class work was not organized in exactly the same way at all sites, with Greek and Czech learners working collaboratively throughout the activities, although the level of collaboration varied, while Romanian learners working individually in parts of the activities. This was the result of limitations in infrastructure. This however allowed the comparison of results and the identification of learning benefits related to the deployment of serious games in different classroom organizational settings. The number of interviews documented in Romania and the Czech Republic also varied in number.

4 Epilogue

4.1 Summary of findings and contribution to the literature

Serious games based on programming can positively contribute to the development of analytical thinking capacity, algorithmic thinking, and reasoning among primary education learners. Programming, which is inherently structured in nature and is based on universal logic that transcends language and cultural barriers, can positively contribute to the development of problem solving mindsets among young learners. Analytical thinking practices are naturally part of programming processes. In order to construct a viable program to a given problem a learner must engage in analytical thinking activities that include recognizing the objective of a given problem, identifying input parameters and resources available for synthesizing a solution, understanding restrictions and rules that adhere a potential solution, evaluating interim and final results in relation to problem objectives, and analyzing potential alternative implementation paths towards optimizing an initial solution.

Programming can be integrated into class practices and wider blended educational processes as a collaborative, social activity that is inclusive, engages all class members, and enhances learning participation, experiences, and outcomes through gamification of the learning process. Gamification can be implemented in the form of achievement rewards and recognition for completing a specific exercise, difficulty levels that introduce a sense of progress towards a higher goal, and rewards that promote long-term engagement with learning processes for completing several difficulty levels of a specific exercise. These gamification elements, when integrated into programming platforms, can promote the engagement of learners with higher order thinking processes, such as analytical thinking, in a playful manner exposing them to algorithmic thinking activities to which learners would otherwise be optionally exposed much later in upper secondary or higher education.

When programming is deployed in educational contexts with primary objective the development of analytical thinking capacity as opposed to building pure ICT competence, adaptations to the program synthesis tools can be introduced so that learners may more effectively focus on the analytical thinking process. Visual representation of commands may help expose learners to the structure of programming and to programming mindsets related to problem solving while reducing the effort required by learners for building competencies related to applying programming syntax. The visual presentations of commands, combined with gamification processes, introduce a sense of fun in the learning process. Learners perceive their engagement with programming activities to be related mostly to problem solving. The term programming does not emerge during engagement, which demonstrates that the primary goal of using programming as a tool and a means towards developing analytical thinking capacity and not as the main learning objective can be achieved through gamification.

When visual programming is deployed as an analytical skill building approach it can be complemented with additional tools that support analytical thinking processes. Semi-structured virtual exploration can be exploited as an additional gamification element through which learners can build intuition on potential solutions before engaging into more precise programming practices. Exploration can be open-ended in order to allow learners to experiment. It can also be to a certain degree directed by controlling the information presented to learners on-screen in order to provide learning support and to steer learners to the right direction in terms of synthesizing a solution to a given problem.

Semi-structured exploration tools adopt the basic concept of a micro-world introduced by Papert (1993) [35]. Micro-worlds, as conceived by Papert, provide learners with enough information for solving a problem while at the same time eliminating unnecessary “noise” not related to the problem at hand. The freedom that is inherent in the open-ended semi-structured exploration is part of the gaming character of this approach. It is attractive to learners and can be used as a motivational tool as it resembles actions learners execute when engaging with arcade entertainment games. The freedom to use the elements presented on the screen without many restrictions beyond their intended function may result into random choices by learners during exploration. In early engagement stages however, these random choices can help learners build intuition on potential implementation paths. In later engagement stages learners are forced to explore in a conscious manner for building an understanding of a particular solution that allows them to precisely and deliberately reproduce the solution via programming. As such, the semi-structured exploration is beneficial to the analytical thinking processes.

On the other hand, semi-structured exploration can be used by learners iteratively in combination with visual programming. In this context, semi-structured exploration offers advantages in terms of allowing learners to recap the steps required for synthesizing a visual programming solution to an exercise that is non-trivial and requires combinations of programming structures in a longer series of commands. In this light, semi-structured exploration and precise programming are complementary activities that when combined enhance analytical skill building learning design.

Furthermore, when linked to school curricula content related to STEM education programming games can promote multidisciplinary learning and the transfer of analytical thinking capacity built through ICT to other subject areas. This can be achieved through the development of broad learning activities that link programming exercises to mathematics and science by requiring the application of skills on categorization, pattern recognition, execution of arithmetic operations, measurements, and other areas for synthesizing a solution.

Finally, the method used for integrating programming games into wider learning activities on building analytical thinking skills can affect learning outcomes. This work views programming as a collaborative activity aimed for classroom deployment. Collaboration in the classroom, however, can take different forms. When programming is used in an inclusive class organization model that engages all learners under teacher mediation the collective achievement of the class may rise. This may be the result of several factors. First, teacher directive questions on identifying analytically objectives, parameters, resources, and rules encourage the sharing of knowledge among peers for a better understanding of analytical thinking processes by the entire group. Learners share knowledge as peers and build on each other’s understanding as well as that of the teacher for the benefit of the class as a whole. Furthermore, teacher direction is combined with the direction introduced by the programming tools through the visual representation of commands that provide implementation hints and the micro-worlds that promote exploration for developing intuition on potential solutions. These two elements of direction in the context of inclusive collaboration of all class members can enhance learning outcomes as compared to learning design that is focused on work in small groups. Similarly, teacher mediation and directive questions de-briefing post game deployment with the engagement of the entire class promote knowledge sharing among peers, narrative explanation of learner programs to their peers that contribute towards the deep understanding of particular solutions, comparison of different learners solutions, and understanding of the concept of optimization.

4.2 Conclusions and future work

This work presented an evaluation of the deployment of programming games towards the development of analytical thinking capacity among primary education learners. The cMinds environment was used for carrying out the evaluation due to its direct orientation on building analytical thinking, as opposed to programming capacity, and due to the gaming elements that allow learners to explore, collaborate, and learn from each other. The evaluation took place in a classroom setting promoting active class discussion and joint exploration of problem solutions in an open environment that promoted peer learning. The evaluation demonstrated that the deployment of programming games is a strong motivational tool for learners for engaging in analytical thinking activities. Gaming elements such as awards and difficulty levels encouraged learners to continue their use of the game engaging in activities in the long run. It further demonstrated that games can be deployed for playfully easing learners to complex thinking patterns and activities to which they would otherwise be exposed at a much later stage of their education. Most importantly, the work demonstrated that the effectiveness of the games as learning tools is highly related to the overall organization of learning activities in which games are integrated as value adding educational tools and that cycles of gaming and debriefing can effectively contribute towards building structured thinking mindsets.

Future work is foreseen in several directions:

First, towards the integration into the cMinds programming suite of some additional puzzles in order to contribute to the development of analytical thinking processes among young learners in primary school.

Second, towards the deployment of the cMinds serious games among younger learners, even in the early grades of primary school. This is possible with cMinds due to the design choices of the software. Specifically, due to the fact that cMinds uses visual presentations of programming commands with an emphasis on visual presentations that help explain the structure and functionality of each. The design all but eliminates the need to introduce limits or other elements that are based on writing skills thus making the software potentially usable by learners in early grades during which writing and reading skills are not well developed. While learners at that age might be able to mostly use the exploration area of the tools, this would still enable them to build analytical thinking capacity.

Finally, the activity can be extended towards the introduction of a new environment and tools for building digital literacy skills and problem solving capacity among young learners. A related tool would address the advanced requirements for digital literacy not only in the ICT industry but also ICT-using sectors. It would expose learners to the deployment of ICT tools in the context of activities that are inspired from the professional world and prepare them for effectively being professionally active in the future in environments in which digital capacity is, now, a requirement. This involves innovation related sectors that are expected to drive economic growth according to the Digital Agenda for Europe and the New Skills for New Jobs Initiative and are typically related to engineering but also in other sectors in which digital skills are necessary inclusion tourism, human resources, agriculture, and more. A related activity would help address the gap between available and industry required skills. It would help address the fact that while there is a lack of as many as 900.000 ICT professionals, youth unemployment may exceed 50% in specific countries leading to social exclusion. These statistics demonstrate the urgent need for introducing initiatives that promote advanced digital literacy. The activity could address the development of digital skill development among youngsters aged 10 to 15 aiming to prevent less the emergence of less than adequate skill sets among young individuals, which is often a result of reduced access to learning opportunities and services, form ever arising, thus promoting equity and inclusion in education. The activity would promote the broadening of career options for individuals at risk of exclusion by raising awareness on professional profiles that will be in demand in the coming years and by building the skills that are necessary for entering the knowledge economy by: increasing access to learning resources through games that will be openly available; empowering learners to take control of their lives by addressing core digital competencies early, in school education; deploying and evaluating serious games as learning tools towards building skills among individuals at risk of social exclusion that will enhance their employability and as a result their capacity to be socially included and civically active; and raising awareness on broadened professional development paths related to innovation

A related effort would deploy active, game-based learning approaches proposed in this work linking gaming to specific learning objectives tied to both school activities, for example STEM education, and work requirements. Specific attention would be paid to promoting the ability of learners to transfer newly developed knowledge to new contexts using mechanisms such as role-playing while at the same time promoting inclusive learning and encouraging participation and engagement in educational processes.

4.3 List of publications

In scientific journals

Tsalapatas, H. (2013), Programming games for logical thinking, EAI Endorsed Transactions on Serious Games 13(1): e4, ISSN-2034-8800, Volume 1, March 2013.

Tsalapatas, H. (2014), Evaluando el uso de juegos de programación para el desarrollo temprano de aptitudes de pensamiento analítico, Novatica, Revists de la Asociacion de Tecnicos de Informatica, Issue 230, October-November 2014, pp. 39-45.

Tsalapatas, H. (2015), EAI Transactions on Serious Games, Evaluating the Use of Programming Games for Building Early Analytical Thinking Skills.

In conference proceedings with review

Tsalapatas, H. (2012), Developing analytical thinking capacity through serious games and programming, Educa On-line Conference, Berlin, Germany, November 28-30, 2012.

Tsalapatas, H., Heidmann, O., Alimisi, R., Tsalapatas, S., Florou, C., Houstis, E. (2012), Game-based learning towards building early analytical thinking skills through visual programming, EduLearn Conference, Barcelona, Spain, July 2-4, 2012.

Tsalapatas, H., Heidmann, O., Alimisi, R., Florou, C., Tsalapatas, S., Houstis, E. (2012), Supporting primary school students in developing analytical and computational skills through the cMinds learning suite, INTED Conference, Valencia, Spain, March 5-7, 2012.

Tsalapatas, H., Heidmann, O., Alimisi, R., Tsalapatas, S., Florou, C., Houstis, E. (2011), Programming concepts as a means for fostering analytical thinking in primary school students, EduLearn Conference, Barcelona, Spain, July 4-7, 2011.

Tsalapatas, H., Heidmann, O., Tsalapatas, S., Alimisi, R., Florou, C., Houstis, E. (2011), Visual programming towards the development of early analytical and critical thinking, Future of Education Conference, Florence, Italy, June 16-17, 2011.

Tsalapatas, H., Heidmann, O., Alimisi, R., Houstis, E. (2013), A serious game- based approach for situated learning of vehicular languages addressing work

needs and cultural aspects, INTED 2013 Conference, Valencia, Spain, March 4-6, 2013.

Tsalapatas, H., Heidmann, O., Alimisi, R., Houstis, E. (2013), English Language Learning through Innovative ICT Solutions that promote Enculturation and Role-playing, H. Tsalapatas, O. Heidmann, R. Alimisi, E. Houstis, Future of Education Conference, Florence, Italy, June 13-14, 2013.

Tsalapatas, H., Heidmann, O., Alimisi, R., Houstis, E. (2013), Serious Gaming towards Culturally Oriented Language Skill Development addressing Work Needs, ECGBL Conference, Porto, Portugal, October 3-4, 2013.

Tsalapatas, H., Heidmann, O., Alimisi, R., Houstis, E. (2013), siLang: Serious Games for Situated Learning of Vehicular Languages addressing Work Needs , project presentation at the LINQ Conference, Rome, Italy, May 16-17, 2013.

Tsalapatas, H., Heidmann, O., Alimisi, R., Tsalapatas, S., Kourias, S., Sillaots, M., Hourmat, B., Tramonti, M., Oie, S., Houstis, E. (2013), Serious Game Design for Vehicular Language Learning Addressing Work Needs, GALA 2013 Conference, Paris, France, October 23-25, 2013.

Tsalapatas, H. (2013), Game-based, Situated Learning of Vehicular Languages addressing Work Needs, H. Tsalapatas, EDUCA On-line 2013, December 3-4, 2013.

Houstis, E., Tsalapatas, H. (2014), Technology in Education, Houstis E., Tsalapatas H., invited keynote speech at the Panhellenic Conference for ICT teachers, Volos, Greece, March 28, 2014.

Tsalapatas, H., Heidmann, O., Tsalapatas, S., Alimisi, R., Houstis, E. (2011), Open-Ended Game-Based Exploration towards Primary Environmental Sustainability Training, EduLearn 2011 Conference, Barcelona, Spain, July 4-6, 2011.

Τσαλαπάτα, Χ., Heidmann, O., Τσαλαπάτας, Σ., Αλιμήση, Ρ., Χούστης, Η. (2011), Εικονικά Πειράματα για Συνεργατική και Διερευνητική Μάθηση στην Πρωτοβάθμια Περιβαλλοντική Εκπαίδευση, 6º Συνέδριο ΤΠΕ, Σύρος, 4-7 Μαΐου 2011.

Tsalapatas, H., Heidmann, O., Tsalapatas, S., Alimisi, R., Houstis, E. (2011), Open-ended Virtual Experiments towards Early Environmental Skill Development, Future of Education Conference, Florence, Italy, June 16-17, 2011.

Tsalapatas, H., Alimisi, R., Heidmann, O. (2011), Environmental Education through Envkids Didactical Framework and ICT Tools, CELMA Conference, Lake District, UK, June 1-3, 2011 .

Tsalapatas, H., Heidmann, O., Mogli, M. (2010), Virtual experimentation towards the development of early environmental sustainability skills, CELDA 2010 Conference, Timisoara, Romania, October 14-17, 2010.

Tsalapatas, H., Heidmann, O., Tsalapatas, S., Alimisi, R., Houstis, E. (2011), Virtual experimentation towards explorative and collaborative environmental primary education, Europrix Academix Network Conference, Graz, Austria, November 11-13, 2010.

Appendix I – Learner interview questions used in evaluation activities in the Czech Republic and Romania

Have you ever been involved in programming?

Was it difficult to understand?

Do you feel that you can use programming now to a certain extent?

Did programming help you solve tasks and make decisions?

What was the most interesting aspect of the tools?

Were the tools attractive?

Did the exploration activity help build a solution to a given exercise?

Did the animated feedback that showed what your program does help make progress towards building a solution?

Which tasks were you able to complete?

Do you feel more confident in solving problems now?

What did you like the most?

Will you use the tool again?

Can the tool make mathematics and science more attractive?

How would you make the tool better?

Is it better to use the tool individually or to collaborate with other learners?

Bibliography

[1] H. Tsalapatas, O. Heidmann, R. Alimisi and E. Houstis, "A Serious Game-based Approach forSituated Learning of Vehicular Languages addressing Work Needs and Cultural Aspects," in *IATED 2013 Conference*, Valencia, Spain, March 4-6, 2013.

[2] D. Autor, F. Levy and R. Murnane, "The skill content of recent technological change: an empirical expoloration," *Quarterly Journal of Economics*, vol. 118, no. 4, November 2003.

[3] European Commission, "New Skills for New Jobs Initiative," [Online]. Available: http://ec.europa.eu/social/main.jsp?catId=568.

[4] European Commission, "The Digital Agenda for Europe," [Online]. Available: http://ec.europa.eu/digital-agenda/.

[5] OECD, "What Makes a School Successful," http://www.oecd.org/pisa/keyfindings/pisa-2012-results-volume-IV.pdf, PISA 2012 report.

[6] OECD, "What Students Know and Can Do," http://www.oecd.org/pisa/keyfindings/pisa-2012-results-volume-I.pdf, PISA 2012 report.

[7] OECD, "What Makes a School Successful," http://www.oecd.org/pisa/pisaproducts/48852721.pdf, PISA 2009 report.

[8] OECD, "What Students Know and Can Do," http://www.oecd.org/pisa/pisaproducts/48852548.pdf, PISA 2009 report.

[9] H. Tsalapatas, "Developing Analytical Thinking Capacity through Serious Games and Programming," in *Educa On-line Conference*, Berlin, Germany, November 28-30, 2012.

[10] H. Tsalapatas, O. Heidmann, S. Tsalapatas, R. Alimisi, C. Florou and E. Houstis, "Visual Programming towards the Development of Early Analytical

and Critical Thinking," in *Future of Education Conference*, Florence, Italy, June 16-17, 2011.

[11] H. Tsalapatas, O. Heidmann, R. Alimisi, C. Florou, S. Tsalapatas, C. Florou and E. Houstis, "Game-based Learning towards Building Early Analytical Thinking Skills through Visual Programming," in *EduLearn Conference*, Barcelona, Spain, July 2-4, 2012.

[12] The cMinds Consortium, "The cMinds learning suite," [Online]. Available: http://cminds.org/index.php?option=com_content&view=article&id=70&Itemid=106.

[13] H. Tsalapatas, C. Florou, R. Alimisi, O. Heidmann, J. Stav and L. S.O., "The cMinds Learning Requirements Report," 2009. [Online]. Available: http://www.cminds.org/documents/D2.1_UserRequirements_509998-2010-COMENIUS.pdf.

[14] European Commission, "European Commission Communication on Opening up Education: Innovative teaching and learning for all through new Technologies and Open Educational Resources," [Online]. Available: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52013DC0654&from=EN.

[15] "National Curriculum in England: Computing Programs of Study," [Online]. Available: http://www.gov.uk/government/publications/national-curriculum-in-england-computing-programmes-of-study/national-curriculum-in-england-computing-programmes-of-study.

[16] MIT Media Lab, "Scratch," [Online]. Available: http://scratch.mit.edu/.

[17] MIT Media Lab, "The Lifelong Kindergarten Group," [Online]. Available: http://llk.media.mit.edu/.

[18] S. Papert, Mindstorms: Children, Computers, and Powerful Ideas, Basic Books, 1993.

[19] Carnegie Mellon University, "The Alice programming environment," [Online]. Available: http://www.alice.org/index.php.

[20] J. Meister, "How Deloitte Made Learning a Game, Harvard Business Review Blog Network," [Online]. Available: http://blogs.hbr.org/2013/01/how-deloitte-made-learning-a-g/. [Accessed 9 September 2014].

[21] J. Stewart, "JRC Report on the Potential of Digital Games for Empowerment and Social Inclusion," [Online]. Available: http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=6579 .

[22] OECD, "PISA," [Online]. Available: http://www.oecd.org/pisa.

[23] Institute of Education Sciences, "2011 TIMMS participants," [Online]. Available: http://nces.ed.gov/timss/results11.asp#countries.

[24] OECD, "2012 PISA participants," [Online]. Available: http://www.oecd.org/pisa/aboutpisa/pisa-2012-participants.htm.

[25] Institute of Education Sciences, "TIMMS," [Online]. Available: http://nces.ed.gov/timss/.

[26] Institute of Education Sciences, "Highlights from TIMMS 2011 Mathematics and Science Achievement of U.S. Forth and Eighth-Grade Students in an International Context," [Online]. Available: http://nces.ed.gov/pubs2013/2013009rev.pdf.

[27] OECD, "PISA 2012 Results: Creative Problem Solving. Students' skills in tackling real-life problems, Volume V," 2012.

[28] European Commission, "The Grand Coalition for Digital Jobs," [Online]. Available: http://ec.europa.eu/digital-agenda/en/digital-jobs-0.

[29] Microsoft, "Microsoft in Education initiative," [Online]. Available: http://www.microsoft.com/education/en-mt/partners-in-learning/Pages/network.aspx.

[30] Google, "Google for Education initiative," [Online]. Available: https://www.google.com/edu/#.

[31] Department for Education, "National curriculum in England: computing programmes of study," [Online]. Available:

https://www.gov.uk/government/publications/national-curriculum-in-england-computing-programmes-of-study/national-curriculum-in-england-computing-programmes-of-study.

[32] T. Lee, "Singapore plans to introduce programming lessons in public schools to boost the economy, TechAsia," [Online]. Available: http://www.techinasia.com/singapore-introduce-programming-lessons-schools-boost-economy/.

[33] Wikipedia, "Seymour Papert," [Online]. Available: http://en.wikipedia.org/wiki/Seymour_Papert .

[34] J. Piaget, Main Trends in Psychology, London: George Allen & Unwin, 1973.

[35] S. Papert, The Children’s Machine: Rethinking School in the Age of the Computer, New York: Basic Books, 1993.

[36] S. Papert and I. Harel, Situating Constructionism, 1st Chapter of Constructionism book, Ablex Publishing Corporation, 1991.

[37] B. Wilson, "Metaphors for Instruction: why we Talk about Learning Environments," *Educational Technology,* vol. 35(5), no. http://carbon.ucdenver.edu/~bwilson/wils95 , pp. 25-30, 1995.

[38] D. Clements, Computers in Elementary Mathematics Education, Englewood Cliffs, NJ, Prentice Hall, 1989.

[39] L. Rieber, "Microworlds," in *Handbook of Research on Educational Communications and Technology, Jonassen, David, H. (ed.), 2nd edition*, Simon and Schuster, 1996, pp. 583-603.

[40] L. Rieber, "Designing Learning Environments that Excite Serious Play," in *Australian Society for Computers in Learning in Primary Education*, Melbourne, Australia, 2001.

[41] Wikipedia, "Vector Graphics," [Online]. Available: http://en.wikipedia.org/wiki/Turtle_graphics.

[42] The Logo Foundation, "The Logo Foundation," [Online]. Available:

http://el.media.mit.edu/logo-foundation/index.html .

[43] LCSI, "MicroWorlds Pro," [Online]. Available: http://www.microworlds.com/solutions/mwpro.html.

[44] LCSI, "MicroWorlds EX," [Online]. Available: http://www.microworlds.com/solutions/mwex.html.

[45] D. M. Fitch, "Kinderlogo," [Online]. Available: http://www.kinderlogo.com/ .

[46] MIT Media Lab, "The MIT Media Lab," [Online]. Available: http://www.media.mit.edu/.

[47] M. Resnick, "Lifelong Kindergarten," [Online]. Available: http://web.media.mit.edu/~mres/papers/CulturesCreativityEssay.pdf.

[48] M. Resnick, "Origins and Principles of the Computer Clubhouse," 2009. [Online]. Available: http://web.media.mit.edu/~mres/papers/Clubhouse/clubhouse-origins.pdf.

[49] Y. Kafai and M. Resnick, "Constructivism in Practice: Designing, Thinking, and Learning in a Digital World," Lawrence Erlbaum Associates Inc, Mahwah, NJ, 1996.

[50] M. Resnick, N. Rusk and S. Cooke, "The Computer Clubhouse: Technological Fluency in the Inner City," High Technology and Low Income Communities, MIT University Press, http://web.media.mit.edu/~mres/papers/clubhouse-chapter.pdf, 1998.

[51] LEGO Group, "LEGO Mindstorms," [Online]. Available: http://www.lego.com/en-us/mindstorms/?domainredir=mindstorms.lego.com.

[52] M. Resnick, F. Martin, R. Berg, R. Borovoy, V. Colella, K. Kramer and B. Silverman, "Digital Manipulatives: New Toys to Think With," in *Chi Conference*, http://llk.media.mit.edu/papers/dig-manip/, 1998.

[53] Arduino, "Arduino," [Online]. Available: http://www.arduino.cc/.

[54] Arduino, "The Arduino programming language reference home page," [Online]. Available: http://arduino.cc/en/Reference/HomePage.

[55] Wiring, "Wiring," [Online]. Available: http://wiring.org.co/.

[56] W. Dann, D. Cosgrove, D. Slater and D. Culbys, "Mediated Transfer: Alice 3 to Java," [Online]. Available: http://www.alice.org/publications/MediatedTransfer.pdf.

[57] B. Moskal, D. Lurie and S. Cooper, "Evaluating the Effectiveness of a New Instructional Approach," [Online]. Available: http://www.alice.org/publications/EvaluatingTheEffectivenessOfANewApproach.pdf.

[58] S. Cooper, W. Dann and R. Pausch, "Alice: A 3-D Tool for Introductory Programming Concepts," [Online]. Available: http://www.alice.org/publications/AToolForIntroProgramming.PDF.

[59] M. Conway, S. Audia, T. Burnette, D. Cosgrove, K. Christiansen, R. Deline, J. Durbin, R. Gossweiler, K. Shiuchi, C. Long, B. Mallory, S. Miale, K. Monkaitis, J. Patten, J. Pierce, J. Shochet, D. Staack, B. Steams and R. Stoakley, "Alice: Lessons Learned from Building a 3-D System for Novices," [Online]. Available: http://www.alice.org/publications/chialice.pdf.

[60] Microsoft, "Kodu Game Lab," [Online]. Available: http://www.kodugamelab.com/.

[61] Τμήμα Μηχανικών Η/Υ, Τηλεπικοινωνιών και Δικτύων, Πανεπιστήμιο Θεσσαλίας, "Creating Games in MS Kodu," 2011. [Online]. Available: http://www.koduplay.gr/.

[62] D. Michael and S. Chen, Serious Games: Games that Educate, Train, and Inform (1st edn), Boston: Thomson Course Technology, 2006.

[63] R. Stone, "Serious Gaming – Virtual Reality's Savior?," in *11th International Conference on Virtual Systems and MultiMedia: Virtual Reality at Work in the 21st Century*, Budapest, 2005.

[64] Federation of American Scientists, published in the Summit on Educational Games, "Harnessing the Power of Video Games in Learning," 2006. [Online]. Available: http://informalscience.org/research/ic-000-000-009-

386/Harnessing_the_Power_of_Video_Games_for_Learning.

[65] K. Subrahmanyam and P. Greenfield, "Effect of Video Game Practice on Spatial Skills in Girls and Boys," *Journal of Applied Developmental Psychology,* vol. 15, no. http://www.sciencedirect.com/science/article/pii/S0360131512000619, pp. 13-32, 1994.

[66] S. De Freitas and M. Oliver, "How can Exploratory Learning with Games and Simulations within the Curriculum be Most Effectively Evaluated?," *Computer and Education,* vol. 46, pp. 249-264, 2006.

[67] S. De Freitas, "Learning in Immersive Worlds," *London: Joint Information Systems Committee,* 2006.

[68] M. Prensky, "Digital Natives Digital Immigrants," *On the Horizon, MCB University Press,* vol. 9, no. 5, 2001.

[69] G. Oblinger and J. L. Oblinger, Educating the Net Generation, Educause, 2005.

[70] T. Metcalf, "Listening to your clients," *Life Association News,* vol. 92, no. 7, pp. 16-18, 1997.

[71] R. Garris, R. Ahlers and J. Driskell, "Games, Motivation, and Learning: a Research and Practice Model," *Simulation and Gaming,* vol. 33(4), no. http://sag.sagepub.com/content/33/4/441, pp. 441-467, 2002.

[72] G. Zicherman and C. Cunningham, Gamification by Design, O' Reilly Media, 2011.

[73] J. Rice, "Assessing higher order thinking in video games," *Journal of Technology and Teacher Education,* vol. 15, no. 1, pp. 87-100, 2007.

[74] J. Kirriemuir and A. McFarlane, "Literature Review in Games and Learning," *A Nesta FutureLab Research report,* vol. report 8, 2004.

[75] J. Kirriemuir and A. McFarlane, "Use of computer and video games in the classroom," in *Level Up: The Digital Games Research Conference,* Utrecht

University, The Netherlands, 2003.

[76] B. S. Bloom, K. J. Rehage, L. W. Anderson and L. A. Sosniak, "Bloom's taxonomy: A forty-year retrospective.," *Yearbook of the National Society for the Study of Education (Chicago: National Society for the Study of Education)*, vol. 93, no. 2.

[77] B. Bloom, Taxonomy of educational objectives handbook I: Cognitive domain., New York: David McKay, 1956.

[78] Quest to Learn, "Quest to Learn," [Online]. Available: http://middleschool.q2l.org/curriculum/ .

[79] T. Connolly, E. Boyle, E. MacArthur, T. Hainey and J. Boyle, "A Systematic Literature Review of Empirical Evidence on Computer Games and Serious Games," *Computers and Education Journal*, vol. 59, no. 2, pp. 681-686, September 2012.

[80] The EnvKids Consortium, "The EnvKids project," [Online]. Available: http://ohmpro.org/envkids/.

[81] European Commission, "The Life Long Learning Programme," [Online]. Available: http://eacea.ec.europa.eu/llp/.

[82] H. Tsalapatas, R. Alimisi and O. Heidmann, "Environmental Education through EnvKids Didactical Framework and ICT Tools," in *CELMA Conference,*, Lake District, UK, June 1-3, 2011.

[83] H. Tsalapatas, O. Heidmann, S. Tsalapatas, R. Alimisi and E. Houstis, "Open-Ended Virtual Experiments towards Early Environmental Skill Development," in *Proceedings of the Future of Education Conference*, Florence, Italy, June 16-17, 2011.

[84] H. Tsalapatas, O. Heidmann, R. Alimisi, S. Tsalapatas and E. Houstis, "Open-ended Game-based Exploration towards Primary Environmental Sustainability Training," in *EduLearn Conference*, Barcelona, Spain, July 4-6, 2011.

[85] The siLang Consortium, "The siLang project," [Online]. Available: http://si-lang.net.

[86] H. Tsalapatas, "Game-based Situated Learning of Vehicular Languages Addressing Work Needs," in *EDUCA On-line Conference*, Berlin, Germany, December 3-4, 2013.

[87] H. Tsalapatas, O. Heidmann, R. Alimisi and E. Houstis, "English Language Learning through Innovative ICT Solutions that Promote Enculturation and Role-playing," in *Future of Education Conference*, Florence, Italy, June 12-14, 2013.

[88] H. Tsalapatas, O. Heidmann, R. Alimisi and E. Houstis, "siLang: Serious Games for Situated Learning of Vehicular Languages addressing Work Needs," in *LINQ Conference*, Rome, Italy, May 16-17, 2013.

[89] H. Tsalapatas, O. Heidmann, R. Alimisi, S. Tsalapatas, S. Kourias, M. Sillaots, B. Hourmat, M. Tramonti, S. Oie and E. Houstis, "Serious Game Design for Vehicular Language Learning Addressing Work Needs," in *GALA Conference*, Paris, France, October 23-25, 2013.

[90] The TALETE Consortium, "The TALETE project," [Online]. Available: http://www.scientix.eu/web/guest/projects/project-detail;jsessionid=6765BAE1576268CDDA14CA6227235EE2?p_p_id=webcontentbrowser_WAR_scientixportlet_INSTANCE_nLk4&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_pos=1&p_p_col_count=.

[91] The EPINOISI Consortium, "The Magic Potion," [Online]. Available: http://www2.media.uoa.gr/epinoisi/index.html.

[92] IBM, "The INNOV8 BPM simulation game by IBM®," [Online]. Available: http://www-01.ibm.com/software/solutions/soa/innov8/index.html .

[93] McGraw Hill, "McGraw Hill Practice Series games," [Online]. Available: http://www.mhpractice.com/ .

[94] McGraw Hill, "McGraw Hill Practice Series Practice Marketing game,"

[Online]. Available: http://www.mhpractice.com/products/Practice_Marketing.

[95] The Learn to Lead project, "The Learn to Lead project," [Online]. Available: http://150.146.65.191/learn2lead/portal/.

[96] European Commission, "Europe 2020 Targets," [Online]. Available: http://ec.europa.eu/europe2020/targets/eu-targets/.

[97] A. Bianchi, S. Barrios, M. Cabrera, R. Cahia, R. Compano, N. Malanowski, Y. Punie, G. Turlea, D. Zinnbauer and C. Centeno, "Revisiting eInclusion: From vision to action," European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS), Sevilla, Spain, 2006.

[98] L. Bleumers, A. All, I. Marien, D. Schurmans, J. Van Looy, A. Jacobs, K. Willaert and F. De Grove, "State of Play of Digital Games for Empowerment and Inclusion: a Review of the Literature and Empirical Cases," JRC Technical Reports, 2012.

[99] M. Makinen, "Digital Empowerment as a Process for Enhancing Citizens' Participation," *e-Learning and Digital Media Journal,* vol. 3, pp. 381-395, 2006.

[100] J. Stewart, L. Bleumers, J. Van Looy, I. A. Marien, D. Schurmans, K. Willaert, F. De Grove, A. Jacobs and G. Misuraca, "Potential of Digital Games for Empowerment and Social Inclusion of Groups at Risk of Social and Economic Exclusion: Evidence and Opportunity for Policy," JRC Scientific and Policy Report, http://ftp.jrc.es/EURdoc/JRC78777.pdf, 2013.

[101] The InLiving game, "The InLiving game," [Online]. Available: http://en.wikipedia.org/wiki/InLiving.

[102] iMinds vzw, "Poverty is not a game," [Online]. Available: http://www.povertyisnotagame.com/?lang=en.

[103] Kognito, "At Risk game," [Online]. Available: http://www.kognito.com/products/highered .

[104] M. Graafland, J. Schraagen and M. Schijven, "Systematic Review of Serious Games for Medical Education and Surgical Skills Training," *The British Journal of Surgery,* vol. 10, no. 99, pp. 1322-30, October 2012.

[105] A. Hanning, N. Kuth, M. Oznan, S. Jonas and C. Spreckel, "eMedOffice: A Web-based Collaborative Serious Game for Teaching Optimal Design of a Medical Practice," *BMC Medical Education,* no. http://www.biomedcentral.com/1472-6920/12/104, 2012.

[106] CliniSpace, "The CliniSpace® application for medical training," [Online]. Available: http://www.clinispace.com.

[107] B. Cowan, H. Sabri, B. Kapralos, F. Moussa, S. Cristancho and A. Dubrowski, "A Serious Game for Off-pump Coronary Artery Bypass surgery Procedure Training," *Studies in Health Technology and Informatics,* vol. Vol. 163: Medicine Meets Virtual Reality 19, no. DOI: 10.3233/978-1-60750-706-2-147, pp. 147-149.

[108] Wikipedia, "Experiential learning," [Online]. Available: http://en.wikipedia.org/wiki/Experiential_learning.

[109] D. Kolb, Experiential learning: experience as a source of learning and development, Englewood Cliffs, N.J. : Prentice-Hall, Inc., 1984.

[110] J. Dewey, Experience and Education, New York: Collier Books. (Collier edition first published 1963), 1938.

[111] K. Lewin, "Action research and minority problems," *Journal of Social Issues,* vol. 2, pp. 34-46, 1946.

[112] P. Jarvis, Adult and continuing education. Theory and practice., London: Routledge, 1995.

[113] P. Jarvis, "Learning," YMCA George Williams College, ICE301 Lifelong Learning, Unit 1, London, 1994.

[114] P. Jarvis, Adult Learning in the Social Context, London: Croom Helm, 1987.

[115] D. Boud, "Locating Immersive Experience in Experiential Learning,"

Learning to be professional through a higher education e-book, Univesity of Surrey, vol. Chapter A8, 2010.

[116] D. Boud and G. Feletti, The challenge of problem-based learning (2nd ed.)., London: Kogan Page, 1997.

[117] Wikipedia, "Active Learning," [Online]. Available: http://en.wikipedia.org/wiki/Active_learning.

[118] M. Prince, "Does active learning work? A review of the research," *Journal of Engineering Education,* vol. 93, no. 3, pp. 223-331, 2004.

[119] C. Bonwell and J. A. Eison, "Active learning: creating excitement in the classroom," ASHEERIC Higher Education Report No. 1," George Washington University, Washington, DC, 1991.

[120] R. Felder and R. Brent, "Active learning: An introduction," *ASQ Higher Education Brief,* vol. 2, no. 4, 2009.

[121] J. E. Zull, From brain to mind: Using neuroscience to guide change in education, Sterling, VA: Stylus Publishing, 2011.

[122] S. A. Ambrose, M. W. Bridges, M. DiPietro, M. C. Lovett and M. K. Norman, How learning works: 7 research-based principles for smart thinking, San Francisco: Jossey-Bass, 2010.

[123] W. Berry, "Surviving lecture: a pedagogical alternative," *College Teaching,* vol. 56, no. 3, pp. 149-154, 2008.

[124] A. W. Chickering and Z. F. Gamson, "Seven Principles for Good Practice in Undergraduate Education," *AAHE Bulletin 39,* March 1987.

[125] J. Jensen, T. Kummer and P. d. M. Godoy, "Improvements from a flipped classroom may simply be the fruit of active learning," *CBE-Life Sciences Education Journal,* March 2015.

[126] H. Barrows, "Problem-based learning in medicine and beyond," *New Directions for Teaching and Learning, Jossey-Bass Publishers,* vol. 68, Winter 1996.

[127] J. Savery, "Overview of problem-based learning: definition and distinctions," *Interdisciplinary Journal of Problem-based Learing,* vol. 1, no. 1, p. Article 3, 2006.

[128] R. Fogarty, Problem Based Learning and Other Curriculum Models for the Multiple Intelligences Classroom, Australia: Hawker Brownlow Education, 1997.

[129] W. Hillman, "Learning how to learn: problem based learning," *Australian Journal of Teacher Education,* vol. 28, no. 2, 2003.

[130] D. Woods, R. Felder, A. Rugarcia and J. Stice, "The Future of Engineering Education. III. Developing Critical Skills," *Chemical Engineering Education,* vol. 34, no. 2, p. 108–117, 2000.

[131] S. Seltzer, S. Hilbert, J. Maceli, E. Robinson and D. Schwartz, "An active approach to calculus," in *Bringing problem-based learning to higher education: Theory and practice, L. Wilkerson & W. H. Gijselaers (Eds.)*, San Francisco, Jossey-Bass, 1996, pp. 83-90.

[132] W. H. Gijselaers, "Connecting problem based practices with educational theory," in *Bringing problem-based learning to higher education: Theory and practice, L. Wilkerson & W. H. Gijselaers (Eds.)*, San Francisco, Jossey-Bass, 1996, pp. 13-21.

[133] Stanford University, "Problem-based learning," *Stanford University newsletter on teaching,* vol. 11, no. 1, winter 2001.

[134] B. Hutchings, "Principles of enquiry-based learning," Centre for Enquiry-Based Learning, University of Manchester, Manchester, 2006.

[135] W. C. J. Kyle, "The distinction between inquiry and scientific inquiry and why high school students should be cognizant of the distinction," *Journal of Research on Science Teaching,* vol. 17, p. 123–130, 1980.

[136] P. Kirshner, J. Sweller and R. Clark, "Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching,"

Educational Psychologist, vol. 41, no. 2, pp. 75-86, 2006.

[137] D. E. Egan and B. J. Schwartz, "Chunking in recall of symbolic drawings," *Memory and Cognition,* vol. 7, p. 149–158, 1979.

[138] R. Jeffries, A. Turner, P. Polson and M. Atwood, "Processes involved in designing software," in *Cognitive skills and their acquisition, J. R. Anderson (Ed.),* Hillsdale, NJ, Lawrence Erlbaum Associates, Inc, 1981, p. 255–283.

[139] J. Sweller and G. A. Cooper, "The use of worked examples as a substitute for problem solving in learning algebra," *Cognition and Instruction,* vol. 2, pp. 58-89, 1985.

[140] C. Hmelo-Silver, R. Duncan and A. C. Clark, "Scaffolding and achievement in problem-based and inquiry learning: a response to Kirshner, Sweller, and Clark," *Educational Psychologist,* vol. 42, no. 2, pp. 99-107, 2007.

[141] Wikipedia, "Gamification," [Online]. Available: http://en.wikipedia.org/wiki/Gamification.

[142] Fora.tv, "How Applebee's drives sales with gamification," [Online]. Available: http://fora.tv/2014/06/12/How_Applebees_Drives_Sales_with_Gamification/beeblock_how_applebees_gamified_employee_of_the_month.

[143] The Game of Work, "The Game of Work," [Online]. Available: http://www.gameofwork.com/index.html.

[144] C. Coonradt, The Game of Work: how to enjoy work as much as play, Game of Work, 1984.

[145] S. Merriam, Introduction to qualitative research, San Francisco: Jossey Bass, 2002.

[146] R. Yin, Qualitative research from start to finish, London: The Gilford Press, 2011.

[147] R. Clarke, "Research models and methodologies," in *HDR Seminar Series, Faculty of Commerce, University of Nebraska*, Lincoln, 2005.

[148] J. Creswell, Research design, Los Angeles: Sage Publications, 2014.

[149] J. Platt, "“Case study” in American methodological thought," *Current Sociology,* vol. 40, pp. 17-48, 1992.

[150] R. K. Yin, Case study research: Design and methods (4th ed.). (First published in 1984), Thousand Oaks, CA: Sage, 2009.

[151] K. Lewin, Field theory in social science; selected theoretical papers. D. Cartwright (ed.), New York: Harper & Row, 1951.

[152] B. Tedlock, "From participant observation to the observation of participation: The emergence of narrative ethnography," *Journal of Anthropological Research,* vol. 47, p. 69–94, 1991.

[153] A. Giorgi and B. Giorgi, "Phenomenology," in *Qualitative psychology: A practical guide to research methods, Jonathan A. Smith (Ed.)*, Los Angeles, Sage, 2009, p. 26–52.

[154] C. Kohler Reissman, Narrative Analysis (Qualitative Research Methods), SAGE, 1993.

[155] Ι. Θ., Ποιοτικές Μέθοδοι Έρευνας στις Κοινωνικές Επιστήμες, Εκδόσεις Κριτική.

[156] C. Robson, Real world research, John Wiley and Sons Ltd, 2002.

[157] L. M. Given, The Sage encyclopedia of qualitative research methods., Los Angeles, Calif.: Sage Publications, 2008.

[158] M. Gunderson and B. Aliaga, Interactive statistics, Upper Saddle River, NJ: Pearson Education, Inc., 2000.

[159] D. Muijs, Doing quantitative research in education with SPSS, 2nd edition,, Los Angeles: Sage Publications, 2010.

[160] D. Phillips and N. Burbules, Postpositivism and educational research, Lanham, MD: Rowman & Littlefield Publishers, 2000.

[161] H. H. Wideman, R. D. Owston, C. Brown, A. Kushniruk, H. F. and K. C.

Pitts, "Unpacking the potential of educational gaming: A new tool for gaming research," *Simulation and Gaming,* vol. 38, no. no 1, pp. 10-30, 2007.

[162] E. Scanlon, A. Jones, J. Barnard, J. Thompson and J. Calde, "Evaluating Information and Communication Technologies for Learning,," *Educational Technology and Society,* vol. 3(4), no. ISSN 1436-4522, 2000.

[163] S. C. Ehrmann, "The Flashlight Approach: Evaluation Educational Uses of Technology," 2011.

[164] A. McDougall and D. Squires, "An Empirical Study of a new Paradigm for Choosing Educational Software," *Computers and Education,* vol. 25, no. 3, pp. 93-103, November 1995.

[165] D. Dockerman, "5 Ways Teachers Can Evaluate Educational Games," [Online]. Available: http://mashable.com/2012/05/18/educational-video-games-how-to/.

[166] Gamification Wiki, "Game Mechanics," [Online]. Available: http://gamification.org/wiki/Game_Mechanics.

[167] W. Barendregt and M. Bekker, "Exploring the potential of the drawing intervention method for design and evaluation by young children," *CHI '13 Extended Abstracts on Human Factors in Computing Systems,* 2013.

[168] B. Zaman, "Evaluating Games with Children," in *Proceedings of Interact 2005 Workshop on Child computer Interaction: Methodological Research*, 2005.

[169] N. Walliman, Social research methods, Los Angeles: Sage Publications, 2006.

[170] H. Tsalapatas, O. Heidmann, R. Alimisi, C. Florou, S. Tsalapatas and E. Houstis, "Supporting Primary School Students in Developing Computational Thinking Skills through the cMinds Learning Suite," in *INTED Conference,* Valencia, Spain, March 5-8, 2012.

[171] H. Tsalapatas, O. Heidmann, R. Alimisi, S. Tsalapatas, C. Florou and E. Houstis, "Programming Concepts as a Means of Fostering Analytical Thinking in Primary School Students," in *EduLearn Conference*, Barcelona,

Spain, July 4-7, 2011.

[172] Greek Ministry of Education, "Primary school curricula on informatics in Greece," [Online]. Available: http://dide.zak.sch.gr/plinetza/yliko/programma_spoudw_tpe_dimotiko.PDF.

[173] Greek Ministry of Education, "Primary school curricula on mathematics in Greece," [Online]. Available: http://www.pi-schools.gr/programs/depps/ .

[174] European Schoolnet, "Survey of schools: ICT in education, country profile: Romania," [Online]. Available: https://ec.europa.eu/digital-agenda/sites/digital-agenda/files/Romania%20country%20profile.pdf.