Guided Participatory Research on Parallel Computer Architectures for K-12 Students Through a Narrative Approach

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Abstract: The approach to computer science (CS) education is typically geared towards the knowledge of the principles behind information technology, but there are social indicators that it overlooks some important educative aspects such as thinking competences and social attitudes. Such aspects play a fundamental role when bringing CS education to the K-12 level. In order to enable a truly educational experience, we propose to bring specific CS research problems within reach of K-12 students, because the active knowledge construction process that takes place during research requires children to be engaged with all of their knowledge, skills and attitudes. This poses the challenge of overcoming the knowledge gap of students, which we address by means of a synergistic cooperation of CS experts and educators. More specifically, we propose the narrative approach as the key enabler for CS participatory research with K-12 students.

1 INTRODUCTION

Computer science (CS) and the technologies it enables now lie at the heart of the way students live their lives, especially in school and entertainment environments. The ubiquity of information technology is frequently cited to support inclusion of CS in secondary education. The starting point for this work is that even learning-objective-oriented approaches to CS education (Sawyer, 2009; Pasternak, 2012) in many cases end up accounting only for some educational elements (e.g., programming skills), while leaving the remaining ones (e.g., social skills, self-confidence, motivation, curiosity) to other disciplines (psychology, pedagogy, sociology). In practice, however, any CS curriculum develops social attitudes and thinking skills, even though they are not explicitly accounted for in curriculum design. The unmistakable proof of this matter of fact is given by a generalized lack of interest in science curricula in secondary and tertiary education. Another side effect is that thinking competences such as creative, critical and care thinking are not evolved to the same extent of technical knowledge and skills.

In order to overcome this gap, we value the research experience as a highly educative one, since it consists of an active knowledge construction process where the subject is engaged with all of his knowledge, skills and attitudes. For this reason, we aim at bringing research experiences in CS within reach of the cognitive capabilities of K-12 students. It is in fact at this stage of education that long-term attitudes start shaping up.

In order to overcome the common “black-box” approach of children to the media-rich electronic devices that are pervasive in their lives (e.g., smartphones, game consoles, laptops, etc.), the object of the proposed research experience will be the prototype implementation of a networked parallel computer architecture, which provides the needed “intelligence” to the above devices.

The main challenge we face in this project is to adjust technical depth, contextualization, and exemplification to the audience’s stage of cognitive development. From a pedagogical perspective, an effective way of making complex concepts accessible to young students is the narrative approach, since narrative thinking reflects the basic and powerful forms in which we gain knowledge of the world (Egan, 1986). Therefore, stories support the possibility to explain phenomena by creating

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narrative forms of models of industrially created objects (Fuchs, 2013).

For the sake of our research framework with children, we identify grid street plans of modern cities as an effective metaphor of on-chip interconnection networks, which provide the needed communication and integration function to modern parallel computer architectures.

For the success of the proposed approach, the synergistic and inseparable cooperation of pedagogists and CS researchers at all stages of the implementation is a mandatory requirement. In fact, such cooperation should complement depth and breadth of knowledge about CS with pedagogical content knowledge (Cochran et al., 1993).

2 MOTIVATION

Today, teaching science at school is one of the major challenges for education. The Eurydice Report on the development of key competence at school in Europe (2012, p. 43) stresses the following factors:

- young people lack of basic skills in mathematics and science;
- there is a declining number of higher education graduates in MST (mathematics, science and technologies) fields.

Since education has a pivotal role in order to reverse this negative trend, what seems to be urgent is the necessity to impart new vigour to science education in order to raise student's interest, knowledge and skills. Our contribution is thus a methodology for the realization of an educative experience in science education at school.

We consider the present situation of science education to have its roots early in the school system, where abilities, preferences and disabilities start shaping up. Thus, we develop educational strategies for students at the K-12 level.

While CS is firmly established in higher education, introducing K-12 students to CS remains a major challenge, since it implies to address the pedagogical issues associated with adapting the level of technical detail to students at varying levels of cognitive development (Knobelsdorf, 2013). Recent learning theories such as constructivism, activity theory, and situated or distributed cognition theory, as well as work conducted in the interdisciplinary field of the learning sciences, are trying to tackle the problem, although this effort is still in the early stage.

One relevant evidence from the application of the constructionism theory is that learners are more likely to be intellectually engaged when they are working on personally meaningful activities and projects. In this direction, designing and creating simple digital objects (a webpage, a small program or a simple hardware device) was shown to rise the curiosity to acquire the foundation of factual knowledge (Knobelsdorf, 2011). However, one common misunderstanding is that there is no reaction of what is studied upon the development of the person learning, upon the tastes, interests, and habits that control student's future mental attitudes and responses. In practice, these personal elements are collaterally formed. This is an evidence that stems from sad matter of facts: for instance, CS education may lead to students that are largely engaged with computer programming, but at the expense of the development of social abilities and skills; moreover, this might not be reflected into the formation of attitudes that decide the uses to which the ability is to be put on.

Another common embodiment of constructivism consists of setting up environments for learning programming such as Logo, Scratch or Lego Mindstorm. Although these learning environments are engaging, students do not automatically obtain a clear and systematic understanding of programming concepts (Meerbaum-Salant et al. 2010). In our approach, the entry point into CS is not simply working with technology, but rather a research experience that leads students to "discover" the basic principles of complex electronic devices of common use.

This choice stems from the awareness that students succeed in developing domain-specific competencies when their learning corresponds to authentic situations, where tasks and problems arise not from pedagogical concerns, but rather from the real-world (Collins, 2006). Because CS knowledge mostly consists of abstract concepts or problem-solving strategies, we propose an effective way of contextualizing this. We thus present a concrete instance (a real prototyping platform) as well as the underlying abstract principle (on-chip networking), so that students not only develop a general understanding of the concept in question, but also learn to apply it in different situations.

3 PROPOSED APPROACH

3.1 Methodology

We target the incorporation of a project-based experiential learning experience into the K-12 students' curriculum in the form of a guided research experience on selected design and optimization issues of a real-life electronic device prototype. *The ultimate objective is to enable the basic understanding of the working principle of modern media-rich electronic devices, AND to foster the "researcher mind-set" in the students.* The goal is that the latter get used to the knowledge construction process of CS researchers, since we identify in the research activity many attributes of an authentic educative experience while teaching the science behind IT.

This holds promise of increasing students' motivation to learn as well, especially in the technology field, thus triggering a positive feedback on future school-choices and professional careers that can potentially reverse current negative trends in the long run. The ultimate reason is twofold. On one hand, students get a "real-time reward" for their uptake of the knowledge construction process: the possibility of making inroads into the working principles of those electronic devices that are pervasive in their life. Students in fact tend to consider them out-of-reach of their knowledge capability because of their complexity. On the other hand, students are brought to the stage where they can explore part of the design space of such devices, through a guided research experience, with positive implications on self-confidence and curiosity.

In practice, our approach aims at bringing participatory-research with children (Christiansen and James, 2008; Mortari, 2009) outside the boundaries of humanistic studies, where it has been mainly experimented so far. Some added values of project-based learning based on a real problem from CS research are:

- In the real world, knowledge (and its application) is integrated, rather than split artificially into subjects. Moreover, problem-solving is not a school exercise with a predefined set of answers but rather a complex engagement of an authentic issue with multiple potential solutions (inquiry-based learning). This feature, first characterized by Dewey (1938), remains the distinctive hallmark of experiential learning, central to our approach.
- It implicitly sets a broad range of learning objectives that contribute to all of the pillars of lifelong education, as identified by Delors (1996): learning to know, learning to do, learning to live together and learning to be.

The research experience needs to be guided by a CS researcher from academia or industry for a number of reasons, associated with his technical expertise as well as with the different educational interaction that he potentially raises in students (Tenenberg, 2010; Fincher, 2013). He can point out some key design choices that students would have never thought about. He can also encourage students to think more deeply about the problems, rather than simply grasping "good enough" answers. Finally, students experience increased relatedness to a technology-related profession, and to the practice that the researcher exposes them to. Simply speaking, the feeling of "serious work", of "complex work made accessible", and of "doing things right" clearly increases students' motivation.

3.2 Experimental Research Setting

Between 2000 and 2005 a fundamental design paradigm shift took place in the field of computer architecture. The application demand for more performance-per-watt, especially in the embedded computing domain, caused traditional monolithic high-performance microprocessors to evolve toward multicore architectures. In practice, the processing workload started to be split among a number of concurrent computation units, thus materializing congruent multiples in performance speed-up and power efficiency. This trend is currently well underway, to the extent that manycore architectures start to appear, that rely on hundreds of concurrent processing units implemented onto the same integrated circuit. The key component of a highly parallel computing architecture consists of an on-chip interconnection network (Network-on-chip, NoC) capable of networking the processing cores together onto the same parallel hardware platform. Further technical details can be found in (Bertozzi and Flich 2012). Our approach therefore aims at familiarizing K-12 students with the paradigms of *computation parallelism* and *on-chip networking*, which are revolutionizing architectures and applications in the embedded computing domain.

For the sake of keeping the research experience focused, it will concern the routing problem in NoCs. This latter consists of finding performance-efficient routing paths for network packets to reach their intended destinations. Feasible solutions to this problem have to meet the deadlock avoidance concern. Deadlock consists of a permanent blocking condition of network traffic due to circular dependencies in the routing channel request pattern. Overall, during the research activity students will have to devise feasible routing algorithms while assessing the absence of such circular dependencies. Moreover, such routing algorithms will be comparatively assessed from the viewpoint of their effects on congestion and implementation complexity.

At this point, the relevant problem of overcoming the knowledge gap of K-12 students arises. Addressing this problem requires a cross-fertilization with findings from pedagogy research.

4 THE FIGURATIVE STRUCTURE

4.1 Narrative Approach

Is it possible to teach very difficult scientific concepts to young students? Different educators and psychologist have considered this question and diverse answers were given.

The psychologist Jerome S. Bruner (1966, p. 33) wrote: “Any subject can be taught effectively in some intellectually honest form to a child at any stage of development”. Following Bruner, narrative and propositional thinking are the ways in which human beings structure their knowledge (Bruner, 1986). Usually, at school, sciences are taught using formal language and logic-scientific thinking (namely the paradigmatic one). Our proposal considers a second opportunity: using the narrative form to introduce formal and scientific knowledge. Developing narrative understanding of the science would complement the introduction of formal explanations of how the world works.

Indeed, the elements of narrative are not foreign to formal scientific understanding (Fuchs, 2013). Stories can be used to deepen our understanding of some physical concepts (e.g., in Fuchs’ work: the gestalt of forces and its aspects), because schematic and metaphoric structures are part of our everyday’s life, in particular of children’s one.

Story form is a cultural universal which ‘reflects a basic and powerful form in which we make sense of the world and experience’ (Egan, 1986, p. 2). Children especially use personal narratives to order and explain the complexity of their experiences of the world (Engel, 1999). Gallas (1994) presents how children talked and wrote about science, and reports on the complexities of the language and the stories they used to understand the world of science. Using narrative forms help children to get introduced to the complexity of the world through an approach that respects the form of their knowledge and their human mind.

In applying this approach to our research experience on parallel distributed computing, we are facing two distinctive and unprecedented challenges:

- The definition of a figurative structure that makes on-chip interconnection networks and their system integration function accessible to K-12 students through a suitable metaphor.
- The application of the figurative structure to an open-situation (i.e., the research experience). Thus, the figurative structure should be realized as a plot, rather than as a full and “static” story serving the purpose of bringing pre-defined concepts within reach of the cognitive abilities of students. The plot of the story would be in fact the metaphor for the constraints and operating conditions of a real multicore processing environment. Pre-defining only the plot enables the students to evolve it and complete the story, by following a driving question provided by the CS researcher. Providing answers to the stated question will enable students to augment the plot with missing details, which correspond to technical solutions to a specific research problem in the physical domain. Solutions to problems will be derived by students in a collaborative way, under the guidance of the CS researcher, who will lead the in-class research.

4.2 The Narrative Approach at Work

The in-classroom research framework we propose will be structured into a seven step methodology:

1- Setting the path to the research experience by an in-class presentation of the CS researcher bridging the gap between students’ pre-knowledge and the concepts needed to start the experience.

2- Definition of a figurative structure capable of overcoming the technical knowledge gap of students with respect to parallel computing and on-chip networking (see Section 4.3).

3- Presentation of the figurative structure to the students, with a clear distinction made between predefined vs. undefined elements. The former ones are the outcome of pre-taken design decisions (e.g., the figurative structure for the routing mechanism) and/or operating conditions in the physical domain (e.g., synchronous operation), while the latter ones represent the available degrees of freedom for design space exploration (e.g., the figurative structure for the routing algorithm).

4- In-classroom collaborative research, where the students will work out their solutions to the routing problem under the guidance of the CS researcher. This will not be done directly, but by reasoning on the corresponding problem in the figurative structure.

5- Selection of the best candidate routing solutions for prototyping on a real on-the-field programmable hardware platform, and definition of a set of quality metrics and experiments for their comparative assessments.
6- Taking the field-programmable hardware platform (FPGA) to the classroom, after the implementation variants of the routing framework have been pre-implemented and made quickly interchangeable. Running the experiments and collection of experimental results that should then be properly structured for discussion (tables, figures).
7- Discussion of experimental results, with the CS researchers having the key role of stimulating the association of observed macroscopic results with the low-level details and effects taking place in the figurative structure of the hardware platform.

The researchers will lead the research activity supporting students to identify questions, formulate hypothesis, design solutions and problem-solving strategies through dialogue and collaborative work groups.

In order to guarantee the feasibility of the methodology, two fundamental requirements need to be fulfilled in the hardware prototype:

- Implementation of a networked multicore system with fast reconfiguration capability of the routing function. Runtime reconfiguration of the routing algorithm should not imply the recompilation of the hardware platform, so to meet timing constraints of a class lecture.
- The platform should be equipped with a graphical user interface for the sake of specifying hardware parameters, collecting statistics and/or monitoring specific functional effects while the system is running. For this purpose, the GUI should reflect the chosen figurative structure, and graphically associate events in the hardware platform with those in the figurative structure.

4.3 The Grid Street Plan Metaphor

The figurative structure of our on-chip interconnection network is realized through the metaphor of a *grid street plan* of a modern city (such as New York City). Grid street plans are the metaphor of 2D mesh topologies for NoCs in the physical domain. The students will therefore explore the design space of NoC routing algorithms by taking routing decisions in a grid street plan. The metaphor is so effective that in the early stage of on-chip networking routing mechanisms were directly inspired by the paradigm of driving directions (Borkar, 1988). The key requirement for the metaphor to hold consists of an initial alignment of the metaphor to the feasibility space of NoCs. In fact, the direct transposition of the grid street plan implementation details (e.g., crossings, roundabouts, traffic lights) to the NoC domain does not result in efficient solutions. For instance, street crossings managed via traffic lights or via the right-hand precedence rule would result in poor communication bandwidth in the electronic domain, since some traffic streams would block other ones although heading to different destinations. As a consequence, the students will move from this consideration and will be guided to design street crossings and grid networks for which the metaphor holds, although the resulting solutions will certainly be a cost-overkill in a real city. In this direction, crossings will be engineered in such a way that every arriving direction is theoretically connected with all other directions in a collision-free way. This implies the implementation of multi-layer street crossings, following the paradigm pictorially illustrated in Figure 1.

Figure 1: Multi-layer street crossing as a metaphor of NoC switches.

5 PREVIOUS RELATED WORK

The challenge to apply the narrative approach to science education has been tackled by several authors in the past (Fuchs 2013, 2007; Corni et al., 2010). We refer to them in order to base our proposal on a reliable pedagogical framework, which is based on the narrative and story structure of human knowledge (Egan, 1986; Bruner, 1986).

In his work, Fuchs (2007) creates figurative conceptual structures for understanding physical processes as a collection of force-dynamic gestalts (quantity, quality, and power). These aspects are structured with the help of metaphoric projections of image schemas. The application of analogy to the various fields of continuum physics lets him recognize a fundamental yet simple conceptual structure - the same as that used in much of human reasoning, not only in physics but also in psychological and social situations.

Another example is provided by Falk, Herrmann, Job, and Schmid (1983), who developed an approach to teach Gibb's thermodynamics stressing the use of substance-like quantities.

We find that the exploitation of the narrative approach for science education is only in the early stage. Our novel contribution consists of using it as a key enabler for a research experience with K-12 students. This implies not just the investigation of a figurative structure for multicore processors and their interconnection system, but also of its suitability for "on-the-field" evolution.

6 CONCLUSIONS

We propose an innovative approach to CS education at the K-12 level. Our main idea consists of bringing research experience on parallel computer architecture within reach of K-12 students, thus jointly developing their knowledge level of the matter as well as their personal attitudes. The key enabler consists of the narrative approach, which we exploit to overcome the technical knowledge gap of the target students.

Our future work consists of further developing the NoC metaphor and the HW/SW prototype for the research experience, and of testing it in Italian middle schools.

An educative research (Creswell, 2002; Mortari, 2007) will be conducted on this experience in order to produce qualitative evidences about the impact of the educative experience on the children's thinking. Qualitative research tools such as video and audiotapes, interviews and written tasks will permit to collect data about the experience itself and the subjective student's responses. A qualitative analysis of these data will guarantee the possibility to describe and assess the expected impact.

REFERENCES

Bertozzi, D., Flich, J., 2012. *Designing Network-on-Chip Architectures in the Nanoscale Era*. CRC Press.

Borkar, S., et al., 1988. *iWarp: An Integrated Solution to High-Speed Parallel Computing*. Proc. Supercomputing.

Bruner, J. S., 1966. *Toward a theory of instruction,* Harvard University Press. Cambridge.

Bruner, J. S., 1986. *Actual minds, possible worlds*, Harvard University Press. Cambridge.

Christiansen, P. and James, A., 2008. (eds) *Research with children. Perspective and practice*, Routledge.

Cochran, K. F., DeRuiter, J. A., King, R. A., 1993. Pedagogical Content Knowing: An Integrative Model for Teacher Preparation, J.*Teacher Education*, 44 (4), pp.263-272.

Collins, A., 2006. *Cognitive Apprenticeship*. In R. K.Sawyer, (ed) *The Cambridge Handbook of Learning Sciences*, Cambridge University Press. Cambridge, pp.47-60.

Corni F., Giliberti E., Mariani, C., 2010. A story as innovative medium for science education in primary school. *GIREP conference*, Reims.

Creswell, J. W., 2002. *Educational Research. Planning, Conducting and Evaluating Quantitative and Qualitative Research*, Pearson Education. New Jersey.

Dewey, J., 1938. *Experience and Education*, Collier Books. USA.

Delors, J., 1996. *Learning: The Treasure Within.* Report to UNESCO of the Int. Commission on Education for the 21st century.

Egan K., 1986. *Teaching as Story Telling,* The University of Chicago Press. Chicago.

Engel, S., 1999. The story children tell. Making sense of the narratives of Childhood, Freeman and Company. USA.

European Commission/EACEA/Eurydice, 2012. *Developing Key Competences at School in Europe: Challenges and Opportunities for Policy*. Eurydice Report. Luxembourg: Publications Office of the European Union.

Falk G., Herrmann F., and Schmid G. B., 1983. Energy forms or energy carriers? *Am.J.Phys*. **51**(12), 1074-1077.

Fincher, S., Knox, D., 2013. The Porous Classroom: Professional Practices in the Computing Curriculum, *IEEE Computer*, 46 (9), pp.44-51.

Fuchs H. U., 2013. From Image Schemas to Narrative Structure in Science, *ESERA Conference*, Cyprus.

Fuchs H. U., 2007. From Image Schemas to Dynamical Models in Fluids, Electricity, Heat, and Motion, *Zurich University of Applied Sciences at Winterthur*. https://home.zhaw.ch/~fusa/LITERATURE/Literature.html.

Gallas, K. 1994. *The languages of learning: How children talk, write, dance, draw, and sing their understanding of the world.* New York: Teachers College Press.

Knobelsdorf, M., Vahrenhold, J., 2013. Addressing the Full Range of Students: Challenges in K-12 Computer Science Education. *IEEE Computer*, 46 (9), pp.32-37.

Knobelsdorf, M., 2011. *Biographische Lern- und Bildungsprozesse im Handlungskontext der Computernutzung*. Doct. dissertation, FU Berlin.

Meerbaum-Salant, O., Armoni, M., Ben-Ari M., 2010. *Learning Computer Science Concepts with Scratch*. In Proc. 6th Int. Workshop Computing Education

Research (ICER 10), ACM, pp.69-76.

Mortari, L. 2009. (ed) *La ricerca per i bambini*. Milano: Mondadori.

Mortari, L. 2007. *Cultura della ricerca e pedagogia*, Carocci. Roma.

Pasternak, A., Vahrenhold, J., 2012. *Design and Evaluation of a Braided Teaching Course in Sixth Grade Computer Science Education*. In Proc. 43rd ACM Technical Symp. Computer Science Education (SICGSE 12), ACM, pp.45-50.

Sawyer, R. K., 2009. *The New Science of Learning*, in R. K. Sawyer, (ed) *The Cambridge Handbook of Learning Sciences*, Cambridge University Press. Cambridge, pp.1-16.

Tenenberg, J., 2010. Industry Fellows: Bringing Professional Practice into the Classroom, *Proc. 41st ACM Techn. Symp. Computer Science Education (SIGCSE 10),* ACM, pp.72-76.