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Design Science Research for Computational Thinking in Constructionist Education: A Pragmatist Perspective

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Abstract. The article examines the modern computer-based educational environment and the requirements of the possible cognitive interface that enables the learner's cognitive grounding by incorporating abductive reasoning into the educational process. Although the main emphasis is on cognitive and physiological aspects, the practical tools for enabling computational thinking in a modern constructionist educational environment are discussed. The presented analytical material and developed solutions are aimed at education with computers. However, the proposed solutions can be generalized in order to create a computer-free educational environment. The generalized paradigm here is pragmatism, considered as a philosophical assumption. By designing and creating a pragmatist educational environment, a common way of organizing computational thinking that enables constructionist educational solutions can be found.
Keywords: computational thinking, constructionist education using technology, design science research, inquiry-based education, pragmatism

Informatinio mąstymo ugdymo konstrukcionistinėje aplinkoje projektavimo moksliniai tyrimai: pragmatistinė perspektyva

Santrauka. Straipsnyje nagrinėjama šiuolaikinė kompiuterinėmis technologijomis grįsta edukacinė aplinka. Aptariami kognityvinės sąsajos, skirtos besimokančiojo įgyjamoms žinioms sieti su realaus pasaulio objektais ar reiškiniais, reikalavimai. Šį susiejimą siūloma realizuoti į ugdymo procesą įtraukiant abdukcinius samprotavimus. Straipsnyje aptariamos praktinės priemonės informatiniam mąstymui ugdyti šiuolaikinėje konstrukcionistinėje aplinkoje, akcentuojant kognityvinius ir fiziologinius aspektus ir jungiant kelių paradigmų teorijas. Pateikta analitinė medžiaga ir siūlomi sprendimai skirti kompiuterinei ugdymo aplinkai, tačiau gali būti apibendrinti ir bendrajai ugdymo aplinkai be technologijų. Filosofine prielaida čia laikoma generalizuota pragmatizmo paradigma. Projektuojant ir kuriant pragmatistinę ugdymo aplinką, randamas informatinio mąstymo ugdymo naudojant konstrukcionistinius edukacinius sprendimus būdas.
Pagrindiniai žodžiai: informatinis mąstymas, konstrukcionistinis mokymas naudojant technologijas, projektavimo moksliniai tyrimai, tyrinėjimais grįstas ugdymas, pragmatizmas

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The history of the concept of *Computational Thinking* originates from the definition given and further developed by Jeannette Marie Wing: "computational thinking is taking an approach to solving problems, designing systems and understanding human behavior that draws on concepts fundamental to computing" (Wing 2008). Computational thinking skills incorporate analytical thinking, engineering thinking, and scientific thinking. Thus, they could be positioned as a kind of necessary skills which every modern student should acquire.

Computing itself is a relatively young scientific discipline. Effective teaching of students' computational thinking skills is a developing area under investigation.

The *problem* that has driven us to carry out this study is that we lack holistic, theoretically based approach to organise a proper educational environment for developing of students' computational thinking skills in practice. It might seem that computers and skills of using technologies improve the skills of computational thinking, because computational thinking "draws on concepts fundamental to computing" (Wing 2008). However, this is not so simple. There are many examples to the contrary provided in the literature (e.g., Coughlan 2015; Richtel 2011). In many educational cases, computers and technology enhanced environment do not work as expected. Instead of improving the abilities and skills of students, the skills and abilities of students are degrading, including the skills associated with computational thinking. In order to solve this problem, we do not recommend avoiding the use of computers in educational environments. Instead, we look for the proper organization of the "computer friendly" educational process.

The aim of this study is to provide an analysis of inquiry based education on psychological and philosophical accounts, focusing on applications of Design Science Research (DSR) and learner's simulation making activities within constructionist educational environment focused on computational thinking.

The main *research questions* we pose in this article are:

1. How should a proper educational environment be arranged in constructionist settings that enables computational thinking skills to be systematically developed?
2. How do existing cognitive and philosophical theories provide support for the design of such educational environment?

We need to provide solutions for navigation and motivation of students, including different educational environments for schoolchildren (Dagienė and Sentance 2016), as well as evaluation of the acquisition of such skills (Dolgopolovas et al. 2016).

No doubt that in order to arrange a proper constructionist educational environment to develop computational thinking skills, an integrated approach is needed. This is especially important for STEM (Science, Technology, Engineering, and Mathematics) education. Wing wrote:

> Computational thinking is a kind of analytical thinking. It shares with mathematical thinking in the general ways in which we might approach solving a problem. It shares with engineering thinking in the general ways in which we might approach designing and evaluating a large, complex system that operates within the constraints of the real world. It shares with scientific

> thinking in the general ways in which we might approach understanding computability, intelligence, the mind and human behavior. (Wing 2008)

Such an integrated educational process should be based on a properly designed constructionist environment. A "proper" environment includes the appropriate "cognitive interface" provided to a student. This cognitive interface serves as an intermedium between the extended educational environment, which includes a computer with an appropriate programming interface, and the cognitive processes and epistemological actions of students. All this allows to correctly direct the "flow" of the constructionist learning process.

We utilise pragmatist approach of inquiry-based education for scientific inquiry, based on models and simulations development, incorporate abductive reasoning and the findings of the DSR theory as discussed in the following sections.

Inquiry-Based Education and Computational Thinking Skills in Constructionist Settings

In this section, we discuss the educational aspects of scientific inquiry. Then, we link to computational thinking skills, which are acquired by students during the learning process. We start with the following question: what is scientific or engineering inquiry, and why is it important for all levels of education? There is a strong opinion (National Research Council 2000; Jadrich 2011) that students should not only learn science and scientific methods, but also should have the opportunity to "do science. This vision for science teaching stems directly from the educational imperative to develop scientifically literate students" (Jadrich 2011). Students can become scientifically literate if they participate in practical scientific activities. Moreover, this can be applied to all students at any level of educational programs in schools, as well as in universities. The practical implementation of educational technology based on scientific inquiry is a complex and challenging task (Flick and Lederman 2006; Jadrich 2011). Learning of scientific content corresponds to the highest levels of Bloom's taxonomy. "Consequently, learning to think and act like a scientist is much more difficult to do than just learning about scientific content" (Jadrich 2011).

Scientific inquiry can be defined as a process or result oriented activity. For instance, the following definition attempts to define scientific inquiry, describing the activities of scientists. Scientific inquiry (1) begins with a scientific question; (2) is a hands-on activity; (3) is a set of specific methods and practices used by scientists; (4) is a set of reasoning strategies or skills needed while driving a scientific process (Flick and Lederman 2006; Colburn 2000). Another solution is to define scientific inquiry using a result-oriented approach (Jadrich 2011). What is the primary goal of scientific activity? We share the opinion (Jadrich 2011; Nersessian 2010; Windschitl et al. 2008) that the primary goal of science is scientific models, and the aim of scientific work is to develop, test, and modify the scientific model of the subject of the study. From the engineering and pragmatist positions, the model can be defined as "a description of some system intended to predict what happens if certain actions are taken" (Bratley et al. 2011; extended by Zeigler 1975).

First, a set of the model components need to be specified. Each component is described by a set of input, output, and state variables. Then the experimental frame is defined as the set of all descriptive variables. Depending on the chosen level of simplification, various experimental frames can be determined (Zeigler 2014).

Generally, we could name the process of development, testing, evaluating and modification of a model as simulation. These operations with the model should take place eventually, and therefore it can be described as a simulative modelling process or simply a simulation. The reason why we focus on it follows from the nature of the simulation. Scientific activity in the design (development, testing, evaluation and modification) of simulations as artefacts is closely related to the cognitive activity of constructing mental simulations and simulative reasoning (Nersessian 2010). Summing up, scientific inquiry can be defined as an activity in the design of scientific simulations, and one of the key goals of scientific work is the design of model-based scientific simulations.

Why are simulations so important? The process of designing simulations provides a part of the cognitive interface enabling the learner's relevant cognitive activities of constructing and grounding of mental models. We will discuss this in more detail. The definition of a model-based simulation is based on the following meanings (Landriscina 2013): (1) The meaning of a system. A system is a collection of different elements whose combination yields results that are unobtainable by the elements alone. Therefore, the system is more than the sum of its parts; (2) The definition of a model. A model is a simplified representation of a real or imagined system; (3) A simulation could be defined on the basis of (1) and (2): a simulation is an interactive representation of the system to be studied, based on a model of the system. This definition has a wider meaning than the traditional view of simulations as a dynamic set of interactive representations. Basically model-based simulations are associated with cognitive activity of students and with the process of constructing appropriate mental models (Landriscina 2013). This approach to simulations also improves learning related cognitive processes, and facilitates modification, construction or replacement of appropriate cognitive structures (Mayer 2009). These processes include enhancement of "cognitive processes that are crucial to learning, such as: selecting key information; organizing this information into a cognitive structure; integrating this new information into previous knowledge; accessing and creating appropriate analogies and metaphors; generating inferences; reorganizing cognitive structures" (Jadrich 2011). One should mention an alternative – a cybernetic approach based on engineering traditions. This cybernetic approach has roots in the technique of representing any system in the form of a "black box" with a certain behaviour. Typically, the aim of a simulation is to observe the dynamic behaviour of the model of a real system. Thus, a person, especially with engineering experience, could view modelling as something superfluous, complex and not essential, especially for educational needs. The model can be considered more important than its simulation, and one can confine himself to the learning task only with the use of modelling. At the same time, educational simulations are usually seen as an example of the use of information and communication technology (ICT) tools, so the effectiveness of such a "traditionally understandable" educational process based on simulations can be questionable. This article focuses on simulation-*making* rather than simulation-*using* activities, although the role of simulation as an ICT tool is not completely rejected.

The constructionist approach focuses on the creation of physical or mental "things" (artefacts) during instruction and student interaction with these artefacts in order to facilitate knowledge (Papert 1980). Focusing on simulation making, simulating using activities can be an alternative in some cases depending on the available learning environment. Implementing the engineering point of view, modelling and simulations can be defined more generally as follows (Raczynski 2014): modelling as a link between real systems and models, and simulation as the relationship between models and computers.

Another important aspect is a simulative scientific reasoning. A scientific reasoning based on simulations of mental models was developed by Nancy Nersessian (2010). The mental model corresponds to the conceptual model, which is built on the first stage implementing model-based simulation activities. A properly designed learning process should implement a unique mapping between model-based cognitive simulations and computer simulations based on models that must be designed during the educational activity. This mapping can be provided by a teacher for example in the form of co-mediated teaching. The presented ideas of intermediate conceptual models and educational activities based on simulations provide a clear link to the environment aimed at acquiring computational thinking skills. For example, there is evidence of conceptual support for acquisition of computational thinking skills practically applied in the contest-based educational environment (Dagiene and Stupuriene 2016, Izu et al. 2017). As will be discussed in the following sections, an approach that focuses on developing a learner's conceptual models as intermediaries for his or her cognitive grounding will provide a solution to the computational thinking skills to be acquired. In this aspect, the set of computational thinking skills can serve as a kind of criteria for evaluating the effectiveness of the educational process, with an emphasis on epistemological and cognitive educational aspects. Such an assessment is aimed at rooting the process of justification that takes place in the process of the students' abductive reasoning. We will discuss this in more detail in the following sections.

Inductive-Deductive Reasoning Scheme and Educational Aspects

Computational pedagogy is an example of one possible approach to arranging of the educational environment in the constructionist manner and is especially relevant for the introductory level education. Such pedagogy allows "cycle back and forth between the inductive and deductive approaches to learning" (Yasar and Maliekal 2014) with the assistance of modelling and simulation tools. The presented approach consists of two main principles: (1) the principle of designing educational environment based on using modelling and simulations, and (2) the idea of scientific reductionism. There are several important aspects for discussion. First, and this has already been mentioned in the previous section, from the educational perspective, there is a great difference between simulation-*making* and simulation-*using* activities. Moreover, there are many doubts about the effectiveness of simulation-using tools aimed at increasing the learner's motivation and his or her conceptual understanding of scientific topics (National Research Council 2011). Usually the practical implementation of simulation-using predefined software can be considered as a sample of a pre-designed cognitive artefact.

The impact of the artefact in the educational environment can be analysed from different aspects: the system view and the personal view. The effectiveness of educational software is a key motivating factor for educators in favour of including such solutions in the educational process. However, from the learner's point of view, such a cognitive artefact is positioned as another tool with a personal view of its effectiveness (Fig. 1 and Fig. 2). Donald A. Norman (1991: 3) provides the following illustrative example: consider a to-do list. Such a checklist, for example, developed for aircraft pilots, enhances the cognitive abilities of pilots and improves their memory. Therefore, from the point of view of the system, it is a memory enhancer. From the point of view of the pilot or from a personal view, using the list is just another task requiring a different type of activity. Without a checklist, a person should remember all the to-do tasks. In order to use the list, the following tasks must be performed: (1) building a list (in the described case, this is done beforehand by a third person); (2) not forgetting to read the list; (3) reading and interpreting the items on the list.

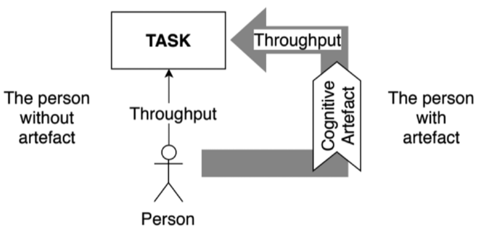

Fig. 1. *System view of a cognitive artefact (adapted from Norman 1991: 3).*

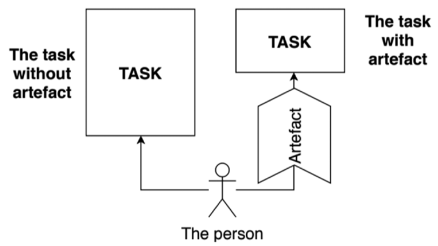

Fig. 2. *Personal view of a cognitive artefact (adapted from Norman 1991: 3).*

To sum up, if from the point of view of the system (read the "teacher") the cognitive abilities are improved, from the personal (student's) view the person participates only in activities (2) and (3), because instead of trying to memorize the elements of the list, the person now should remember only to consult this list. This type of memory degradation is clearly manifested in the daily practice of education. Perhaps this is one of the reasons for the current popular movement towards education without a computer (Richtel 2011). Regarding the use of educational software as an advanced educational tool for constructionist educational platforms, such educational platforms, viewed as cognitive artefacts from the user's point of view, can be very harmful and demotivating. Obviously, during the process of using software, there is some shift in tasks and cognitive processes. Therefore, educational software platforms must be carefully designed and tested. Another obstacle is the problem of bricolage (Papert and Harel 1991). By focusing on using the provided educational platforms, the learner will improve his skills in using the specific software, rather than constructing knowledge for the learning of the topic. The bricolage leads to the “endless debugging of the ‘try-it-and-see-what-happens’ variety” (Ben-Ari 2001). As can be seen, the described aspects are interrelated. Next, the relevance of the use of the ideas of scientific reductionism for the theoretical grounding are discussed. To argue for such a relevance, we first provide a description of inquiry-based educational process: “Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (Colburn 2000). As can be seen from the above description, reducing scientific methods to positivistic and basically quantitative, as scientific reductionism does, would at least be questionable. Other forms of research and the paradigm of research are also important. This is especially true for interdisciplinary engineering areas, such as, for example, research of information systems, where interpretivist and pragmatist paradigms and methods of qualitative research are of paramount importance (Goldkuhl 2012; Walsham 2006). As for cognitive and epistemological aspects, to reduce the scheme of reasoning to that of only inductive-deductive reasoning is doubtful. This can lead to the disabling of the proper grounding process for the students’ cognitive models, and we will discuss this aspect in the next section.

Pragmatist Approach as the Key to Inquiry-Based Education

The psychological aspects of situated cognition give recommendations on how the learning environment should be designed and constructed. Obviously, there is a clear distinction “between natural environments which afford the learning of ‘percepts’ in everyday life, and unnatural environments” (Laurillard 2002). Viewed from a pragmatic position, modelling and simulation is considered as a tool for grounding a student to such an artificial environment in terms of grounded cognition (Barsalou 2008, 2010). Using computer simulation in a constructivist way could be considered as a specific type of grounding through situated simulations (Barsalou 2008; Pezzulo et al. 2013). How can this grounding be practically achieved? Simulation-based learning can be described from the standpoint of the progression of mental models:

> ... beginning with a student’s initial model of an examined system and developing into a target conceptual model-presumably the same one underlying the simulation’s computational model. Moreover, to arrive at the target model, students must first develop their own intermediate conceptual models, which are mental models expressed as cognitive artefacts. (Landriscina 2013)

The presented approach focuses on the conceptual model, as an intermediate for grounding. How can such conceptual models be developed? Following is noteworthy. Conceptual models are based on mental models, so first one has to ask the next relevant question: how does the mental model develop in the human brain? The approach developed by Paul Thagard considers “mental models as representations consisting of patterns of activation in populations of neurons” (Thagard 2010). This cognitive model-based approach overcomes the limitations of sentential models of theoretical abduction

(Magnani 1999; Magnani 2016) and expand C. S. Peirce's ideas of how mental models can "contribute explanatory reasoning" (Peirce 1992) going beyond verbal information and including "visual, olfactory, tactile, auditory, gustatory, and even kinesthetic representations" (Magnani 1999). Considering mental representations as patterns of firing in neural populations, the process of constructing of mental models could be presented as a chain of patterns developing through the process of causal correlations (Magnani 1999). Such an approach could be used to provide explanations of how abduction could generate new ideas. The neural model of abduction presented by Paul Thagard and Terrence C. Stewart (Thagard and Stewart 2011) implements a fully multimodal convolutional model of "creative conceptual combination" describing "many kinds of creativity and innovation, including scientific discovery, technological invention, social innovation, and artistic imagination" (Thagard 2010). The human brain is adapted to powerful learning mechanisms:

> One of these learning mechanisms is an abductive inference, which leads people to respond to surprising observations with a search for hypotheses that can explain them. Like all cognitive processes, this search must be constrained by contextual factors such as triggering conditions that cut down the number of new conceptual combinations that are performed. (Thagard 2010)

It is obvious that such triggering conditions use circumscription (McCarthy 1981) in the form of previous experience to eliminate inapplicable transactions.

How could the abductive reasoning, viewed from pragmatist positions, practically improve the software-based constructionist educational environment towards acquisition and improving of computational thinking skills? First, we should discuss the pragmatist meaning of abduction (Peirce 1992). What are the differences between abduction and the well-known hypothetical-deductive method (Lawson 2015; Magnani 2009)? The essence of abduction or abductive reasoning, as can be seen from the pragmatist perspective, is to provide a way to generate a "clear" hypothesis. How should we describe "clarity"? First, according to Peirce, a clear idea is one that is possible to experience in practice. As he reminds us by the example of the concept of hardness, "there is absolutely no difference between a hard thing and a soft thing so long as they are not brought to the test" (Magnani 2009; Peirce 1992). Regarding the research issue, the learner can test the hypothesis by implementing the simulation and modelling process. Further, C. S. Peirce promotes the idea of "pragmatist" truth as a result of inquiry (Peirce 1992). In this respect, abduction can be considered "as inference to the best explanation, that also evaluates hypotheses by induction" (Magnani 2009). The criteria for choosing the "best" hypothesis among the possible ones are presented in the form of a list of requirements for computational thinking skills that must be acquired and is provided during the co-mediated teaching process. The description of computational thinking (Barr et al. 2011) could be positioned as a pragmatist criterion for evaluating the effectiveness of the process of abductive reasoning.

Enhancing Educational Process by Circumscription and Abductive Reasoning

To formalize the presented approach, a model of modelling (Justi and Gilbert 2002), which describes how students produce their models as mental and as expressed ones, will be used. The presented approach considers modelling as "non-linear creative process comprised of multiple and complex stages mainly concerning with acquiring information about the entity that is being modelled (from empirical observations and/or from previous knowledge); producing a mental model of it; expressing that model in an adequate mode of representation, testing it (through mental and empirical experimentation) and evaluating its scope and limitations" (Justi 2009). From the point of view of cognitive reasoning, the presented "model of modelling" could be generalized as follows. First, the propositional phase is needed to generalize existing information by inductive reasoning. Further, the process of producing mental models based on existing information requires a kind of hypothetical model-based reasoning that should be involved. Therefore, as previously described, a kind of abduction (or grounded abduction in this particular case) is required to be implemented in such a case. The following steps are based on such a classical method of reasoning guided by deduction, requiring some form of conceptualization through an empirical design process. Finally, all these processes are based on existing knowledge and skills, which provide some sort of limitations in the form of circumscriptive reasoning.

This practical model, related to modelling and simulation in education, is generalized by (Landriscina 2013). The processes of abduction and circumscription are extremely important, since they provide a plane dividing simulation using educational methods from simulation-making educational methods. At the same time, the presented approach provides a clear picture of the general practice of eliminating abduction and circumscription from the educational process. This is a kind of common practice based on complete reliance on software tools being like a magic wand. Thus, one could completely defocus your educational goals, focusing not on teaching inquiry and scientific reasoning, but simply training one's additional skills in using software tools. Obviously, the practical implementation of the described approach is not a trivial task. This requires additional efforts for pre- and post-training of teachers, as well as to develop additional educational programs. Moreover, the lack of practical examples for such activities stimulates a strong movement for education without computers, like presented by (Bell, et al., 2009), that is, behind-the-scenes movement for the introduction of abduction and circumscription in pedagogical practice. Another reason for such a popular movement of learning without computers can be a strong influence of instructional techniques, a sort of Instructionism vs. Constructionism as it was defined by Seymour Papert and Idit Harel (1991).

Cognitive Aspects of Design Science Research

The above described cognitive and epistemological aspects require additional efforts to improve the software driven educational environment, which allows to develop inquiry-based constructionist approaches to computational thinking skills. A correct application of educational software tools allows us to organize the learning context in a constructionist manner, that is, to develop a context that is personally significant for the learner. In this regard, the following important remark should be made. We are studying a complex environment that includes both technical and social factors. Technical factors, in addition to hardware, also include software products in the form of educational software or software learning objects. This environment can be characterized as socio-technical. When studying, developing, or implementing such an educational environment, it is necessary to take into account not only the technical aspects of the system, but also social aspects and interactions. Such an environment: has a type of a socio-technical system; includes participants (teachers, students, educational authorities, community, other stakeholders), as well as educational technology, instructional design methods, and educational tools that are (mostly) artefacts, including cognitive artefacts in the form of educational software or software-based learning objects (software as a learning object). We could continue to analyse the previously described aspects from an epistemological standpoint. In general, science can be divided into formal science, such as logic or classical mathematics and factual science, which describes, explains and predicts phenomena and is tested when it gives empirical data. Factual science is divided into natural and social sciences. Natural sciences are focused on objects or phenomena, and the main research activity is to analyse their nature and the reasons for their occurrences (Dresch et al. 2015). Social science describes and reflects the society and the individuals. Research conducted in social science is usually question-based, and it is focused on the researchers' view of the problem in study. Therefore, it is subjective in its nature (Dresch et al. 2015; Romme 2003). Social science could focus on descriptions with attention to a quantitative approach. Another focus, for example in management science, is on solutions to given problems or on artefact creation.

The concept of Design Science as "the Science of the Artificial" was first introduced by Herbert A. Simon (1996). The Design Science focuses on practical solutions and artefacts. The motivational cause of any research can range from research focused on solving theoretical problems and without any or just minor concern on practical applications, or applied research focused on practical solutions (Saunders et al. 2009). Generally, design means creation (or invention) of some new artefacts and its implementation into the area of application. This could be done under existing or non-existing (innovative design) theoretical backgrounds (Vaishnavi and Kuechler 2004).

Design Research focuses on the question of how to design artefacts, while Design Science Research (DSR) focuses on the problem of using design as a research method (Vaishnavi and Kuechler 2004). Therefore, DSR could be positioned as a well-formalized teaching technique, which implements learning through building an educational paradigm and inquiry-based educational methods. Considering the inquiry-based educational process, DSR could provide a set of formalizations for implementing in the practical process of instruction. The main focus of the application of DSR methodology in education is "to teach research" (Vaishnavi and Kuechler 2004). To go further, the artefact is the highlight of our interest, which gives us a target for the design process. Therefore, the design can be described as relating to the artefact, its internal structure and the "crafting" process of the outer environment (Vaishnavi and Kuechler 2004). The next question that should be answered is: Can design be treated as a research process? The answer is affirmative, if the learning process is built as an artefact-oriented, enabling research through the process of designing an artefact. A model for the DSR process focuses on the contribution of new knowledge to be produced. Fig. 3 presents the cognitive aspects of the DSR process.

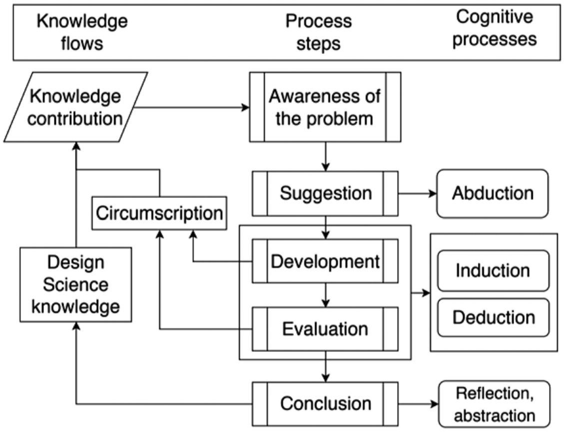

Fig. 3. *The cognitive aspects of the DSR process (adapted from Vaishnavi and Kuechler 2004).*

Towards Computational Thinking by Using Design Science Research Approach

The Design Science Research (DSR) methodology provides a way for the formalization of an inquiry-centred approach based on the development of model-based scientific simulations. This methodology provides a set of analytical techniques based on circumscription and abduction reasoning. The formal structure of research based on DSR very clearly corresponds to educational objectives. This correspondence can provide a set of formalisms for practical implementations of DSR as a set of educational tools. The purpose of DSR as an educational tool is twofold:

(1) First, formalize the process of design of model-based simulations as cognitive artefacts. For this educational purpose, the set of DSR techniques is truncated and adapted for the educational needs. The learner is immersed in a kind of "quasi"-scientific research environment, satisfying inquiry by designing a set of simulations based on provided models of one or another type. Therefore, a practical algorithm could be provided for such a case. The most important remark is the following: the learner should get a clear idea of the meaning of "rigorousness" (with reference to this educational scientific research environment and possible future "real" scientific research). In this educational case, the term rigor stands strictly for adherence to the steps of the algorithm and the instructions of the teacher;

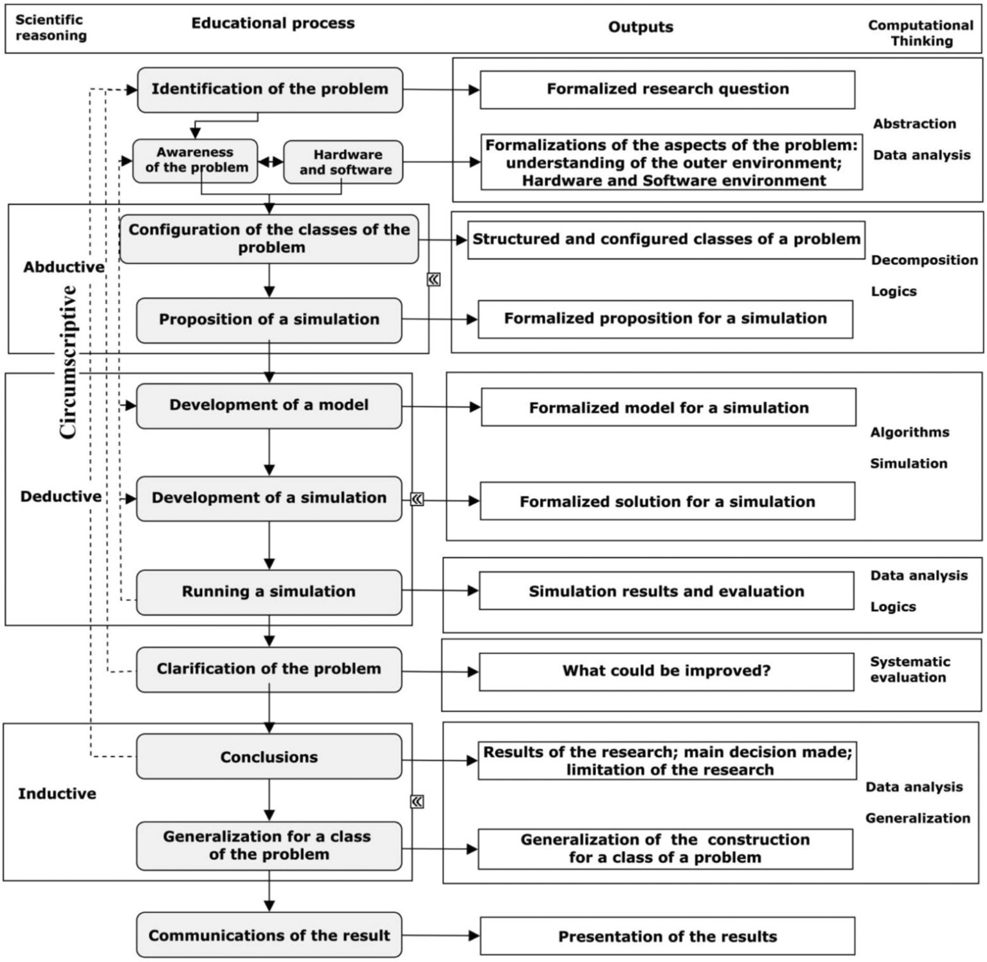

Fig. 4. *Scientific Inquiry centred education and development of Computational Thinking skills (adapted from Dresch et al. 2015: 118).*

(2) Next, introduce DSR as a practical design tool for the future scientific activities of the students. For this purpose, an example of one of the DSR formalisms can be introduced to the students. Such an introduction will provide a clear understanding of the method and its possible future (research) and present (educational tool) applications. At the same time, the educational process could be practically organized on the basis of a sequence of steps that meet the requirements of the DSR. These steps provide a formal basis for inquiry-based research in the form of developing model-based scientific simulations. Fig. 4 presents the methodology and its links with scientific reasoning techniques and computational thinking skills. First, the DSR provides a clear formal structure to ground the learner's cognitive models. The learning process is based on a set of practical activities, including a modelling and simulation process with clear educational goals and in the form of predetermined outputs. Next, DSR provide a kind of instructional scaffolding in

a form of predefined and practical educational steps. As a result, the underlying reasoning processes are mapped to conceptual understanding and skills.

Conclusions

The main input of this research lies in its interdisciplinary approach and integration of cognitive theories to rely on in order to find a possible way of developing computational thinking skills. The provided discussion analyses the pragmatist aspects of the constructionist inquiry-based educational environment. We have focused on the cognitive and epistemological features of the learning process, including descriptions and studies of applications of such important meanings as circumscription and abductive reasoning. Abductive reasoning is considered both from the point of view of the formation of hypotheses, and from the point of view of evaluating hypotheses. This dualistic view-point provides foundations for a model of grounded cognition and allows an inquiry-based educational activities to be organized in a "personally significant" way.

At the same time, the formalities of the DSR provide a framework for the teacher to design the inquiry-based educational environment that is aimed at acquiring computational thinking skills while developing new knowledge. The cognitive aspects of the DSR clearly correspond to previously described epistemological considerations, and at the same time this approach can be viewed as a kind of a universal approach that could be used for various educational topics and in various educational environments, including technology-based STEM. The list of computational thinking skills provides criteria for assessing the effectiveness of the process of the students' abductive reasoning. The methodological paradigm for this approach is clearly not positivistic, and, as discussed in the article, the pragmatist nature of the presented approach provides a way of practical implementation of the results of the study.

So the developed approach presents an outline of integrative methodology that should be considered from both theoretical and practical accounts. Theoretical account should focus on cognitive and epistemological aspects including: neuro-scientific model together with its multilevel extensions; cognitive model such as model of grounded cognition; reasoning model – the model of manipulative abduction. Practical account should focus on educational aspects including: didactic aspects of inquiry-based education and its philosophical considerations; DSR, considering pragmatist perspectives, including epistemological and ontological aspects; cognitive aspects of DSR; pragmatist approach to inquiry-based constructionist education.

Considering neural and cognitive accounts, the following pathway is presented. First, (1) the focus should be shifted from amodal to unimodal (model states are triggered by perception) representations. Under such considerations the role of context becomes very important. This relates to the construction of personally significant content (microworlds, "cognitive" interfaces to PC). Next, (2) coupling of perception and action during the goal achievement (situated action) school takes place. And finally, (3) situated social interaction, social cognition should be developed.

Considering abduction and reasoning methods we should focus on manipulative abduction and the process circumscription. Manipulative abduction provides: (1) grounding of the epistemic acting; (2) stresses the role of external representations and cognitive aspects of acquisition of knowledge (embodiment, situatedness). The circumscription process is especially important in understanding DSR because it generates understanding that could only be gained from the specific act of construction.

Concluding the DSR methodological considerations the following should be mentioned. First, (1) DSR provides a framework for abductive reasoning, which is important for inquiry-based education. The framework integrates the key aspects as: sentential abduction as selective reasoning; model based abduction as a next step for development of epistemic models. Finally, (2) within a pragmatist paradigm, the next of abduction could be described as manipulative abduction thus providing reasoning templates for enhancing constructionist educational environment.

To summarize, the following methodological considerations could be presented:

(1) the main focus should be made on cognitive and epistemological features of the educational process including circumscription and abductive reasoning;

(2) abductive reasoning should be considered both from the point of view of generating hypotheses, and from the point of view of hypothesis evaluation. This provides foundation for a model of grounded cognition and allows inquiry-based educational activity to be arranged in a "personally significant" manner for the learner;

(3) DSR formalisms provide a framework for an educator to design the inquiry-based educational environment which is generally aimed at acquisition of computational thinking skills while developing new knowledge for the learner;

(4) the cognitive aspects of DSR clearly correspond with the described epistemological considerations; the list of computational thinking skills provide a criteria for assessing of the effectiveness of the learner's abduction and abductive reasoning process;

(5) pragmatist nature of the presented approach provides a way for practical educational implementations.

References

Barr, D., Harrison J., Conery, L., 2011. Computational Thinking: A Digital Age Skill for Everyone. *Learning & Leading with Technology 38:* 20-23.

Barsalou, L.W., 2008. Grounded Cognition. *Annual Revue of Psychology* 59: 617-645.

Barsalou, L.W., 2010. Grounded Cognition: Past, Present, and Future. *Topics in Cognitive Science 2*: 716-724. https://doi.org/10.1111/j.1756-8765.2010.01115.x

Bell, T., Alexander, J., Freeman, I., and Grimley, M., 2009. Computer Science Unplugged: School Students Doing Real Computing Without Computers. *The New Zealand Journal of Applied Computing and Information Technology* 13: 20-29.

Ben-Ari, M., 2001. Constructivism in Computer Science Education. *Journal of Computers in Mathematics and Science Teaching* 20: 45-73.

Bratley, P., Fox, B. L., Schrage, L. E., 2011. *A Guide to Simulation*. Springer Science & Business Media.

Colburn, A., 2000. An Inquiry Primer. *Science Scope* 23: 42-44.

Coughlan, S., 2015. Computers 'do not improve'pupil results, says OECD. *BBC News, September 15, 2015*. Available at https://www.bbc.com/news/business-34174796.

National Research Council, 2000. *Inquiry and the national science education standards: A guide for teaching and learning*. National Academies Press.

National Research Council, 2011. *Learning science through computer games and simulations*. National Academies Press.

Dagienė, V., Sentance, S., 2016. It's Computational Thinking! Bebras Tasks in the Curriculum. In A. Brodnik and F. Tort (eds.), *Informatics in Schools: Improvement of Informatics Knowledge and* Perception. *Lecture Notes in Computer Science* vol. 9973, Berlin, Heidelberg: SpringerVerlag, 2016, pp. 28-39. https://doi.org/10.1007/978-3-319-46747-4_3

Dagiene, V., and Stupuriene, G., 2016. Bebras – A Sustainable Community Building Model for the Concept Based Learning of Informatics and Computational Thinking. *Informatics in Education* 15: 25-44. https://doi.org/10.15388/infedu.2016.02

Dolgopolovas, V., Jevsikova, T., Dagiene, V., Savulioniene, L., 2016. Exploration of Computational Thinking of Software Engineering Novice Students Based on Solving Computer Science Tasks. *International Journal of Engineering Education* 32: 1-10.

Dresch, A., Lacerda, D. P., Antunes Jr, J. A. V., 2015. *Design Science Research: A Method for Science and Technology Advancement*. Berlin, Heidelberg: SpringerVerlag.

Flick, L., Lederman, N., (eds.), 2004. *Scientific Inquiry and Nature of Science: Implications for Teaching, Learning, and Teacher Education (Contemporary Trends and Issues in Science Education)*. Berlin: Springer Science & Business Media.

Goldkuhl, G., 2012. Pragmatism vs Interpretivism in Qualitative Information Systems Research. *European Journal of Information Systems* 21: 135-146. https://doi.org/10.1057/ejis.2011.54

Izu, C., Mirolo, C., Settle, A., Mannila, L. and Stupuriene, G., 2017. Exploring Bebras Tasks Content and Performance: A Multinational Study. *Informatics in Education*, *16*(1), pp.39-59. https://doi.org/10.15388/infedu.2017.03

Jadrich, J., 2011. *Learning & Teaching Scientific Inquiry: Research and Applications*: Arlington, VA: NSTA Press.

Justi, R., 2009. Learning How to Model in Science Classroom: Key Teacher's Role in Supporting the Development of Students' Modelling Skills. *Educación Química* 20: 32-40. https://doi.org/10.1016/s0187-893x(18)30005-3

Justi, R. S., Gilbert, J. K., 2002. Modelling, Teachers' Views on the Nature of Modelling, and Implications for the Education of Modellers. *International Journal of Science Education* 24: 369-387. https://doi.org/10.1080/09500690110110142

Landriscina, F., 2013. *Simulation and Learning: A Model-Centered Approach*. New York: Springer-Verlag.

Laurillard, D., 2002. *Rethinking University Teaching: A Conversational Framework for the Effective Use of Learning Technologies*. 2d edition. London and New York: Routledge.

Lawson, A. E., 2015. Hypothetico-Deductive Method. In R. Gunstone (ed.), *Encyclopedia of Science Education,* Dordrecht: Springer Science+Business Media Springer, 2015, pp. 471-472. https://doi.org/10.1007/978-94-007-2150-0_260

Magnani, L., 1999. Model-Based Creative Abduction. In L. Magnani, N. Nersessian, and P. Thagard (eds.), *Model-Based Reasoning in Scientific Discovery*, New York: Kluwer Academic/Plenum, 1999, pp. 219-238. https://doi.org/10.1007/978-1-4615-4813-3_14

Magnani, L., 2009. *Abductive Cognition: The Epistemological and Eco-Cognitive Dimensions of Hypothetical Reasoning*. Berlin, Heidelberg: Springer Verlag.

Magnani, L. ed., 2013. *Model-Based Reasoning in Science and Technology: Theoretical and Cognitive Issues* (Vol. 8). Springer Science & Business Media

Mayer, R. E., 2009. *Multimedia Learning*. Cambridge: Cambridge University Press.

McCarthy, J., 1981. Circumscription – A Form of Non-Monotonic Reasoning. In B. L. Webber and N. J. Nilsson (eds.), *Readings in Artificial Intelligence,* Los Altos: M. Kaufmann, 1981, pp. 466-472. https://doi.org/10.1016/b978-0-934613-03-3.50036-2

Nersessian, N. J., 2010. *Creating Scientific Concepts*. Cambridge, MA: MIT Press.

Norman, D. A., 1991. Cognitive Artifacts. In J.M. Carroll (ed.), *Designing Interaction: Psychology at the Human-Computer Interface*, Cambridge : Cambridge University Press, pp. 17-38.

Papert, S., 1980. *Mindstorms: Children, Computers, and Powerful Ideas*. New York: Basic Books, Inc.

Papert, S.; Harel, I., 1991. Situating Constructionism. *Constructionism* 36: 1-11.

Peirce, C. S., 1992. *The Essential Peirce: Selected Philosophical Writings, Vol.* 2 (1893-1913). Bloomington: Indiana University Press.

Pezzulo, G., Barsalou, L. W., Cangelosi, A., Fischer, M. H., McRae, K., Spivey, M., 2013. Computational Grounded Cognition: A New Alliance Between Grounded Cognition and Computational Modeling. *Frontiers in Psychology* 3: 612. https://doi.org/10.3389/fpsyg.2012.00612

Raczynski, S., 2014. *Modeling and Simulation: The Computer Science of Illusion*. New York: John Wiley & Sons.

Richtel, M., 2011. A Silicon Valley School That Doesn't Compute. *The New York Times,* October 22, 2011. Available at https://www.nytimes.com/2011/10/23/technology/at-waldorf-school-in-silicon-valley-technology-can-wait.html.

Romme, A. G. L., 2003. Making a Difference: Organization as Design. *Organization Science* 14: 558-573. https://doi.org/10.1287/orsc.14.5.558.16769

Saunders, M., Lewis, P., Thornhill, A., 2009. *Research Methods for Business Students.* 5th edition. Harlow, Essex: Pearson Education.

Simon, H. A., 1996. *The Sciences of the Artificial.* Cambridge, MA: MIT press.

Thagard, P., 2010. How Brains Make Mental Models. In L. Magnani (ed.), *Model-Based Reasoning in Science and Technology: Theoretical and Cognitive Issues*, Berlin: Springer, pp. 447-461. https://doi.org/10.1007/978-3-642-15223-8_25

Thagard, P., 2010. How brains make mental models. In Model-based reasoning in science and technology (pp. 447-461). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-15223-8_25

Thagard, P., Stewart, T. C., 2011. The AHA! Experience: Creativity Through Emergent Binding in Neural Networks. *Cognitive Science* 35: 1-33. https://doi.org/10.1111/j.1551-6709.2010.01142.x

Vaishnavi, V., Kuechler, W., 2004. Design Research in Information Systems. Available at http://www.isworld.org/Researchdesign/drisISworld.htm.

Walsham, G., 2006. Doing Interpretive Research. *European Journal of Information Systems* 15: 320-330. https://doi.org/10.1057/palgrave.ejis.3000589

Windschitl, M., Thompson, J., Braaten, M., 2008. Beyond the Scientific Method: Model-Based Inquiry as a New Paradigm of Preference for School Science Investigations. *Science Education* 92: 941-967. https://doi.org/10.1002/sce.20259

Wing, J. M., 2008. Computational Thinking and Thinking about Computing. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 366: 3717-3725. https://doi.org/10.1098/rsta.2008.0118

Yasar, O., Maliekal, J., 2014. Computational Pedagogy: A Modeling and Simulation Approach. *Computing in Science & Engineering* 16: 78-88. https://doi.org/10.1109/mcse.2014.60

Zeigler, B. P., 1975. Simulation Based Structural Complexity of Models. *International Journal of General Systems* 2*:* 217-223.

Zeigler, B. P., 2014. *Object-Oriented Simulation with Hierarchical, Modular Models: Intelligent Agents and Endomorphic Systems*. Saint Louis: Elsevier Science.