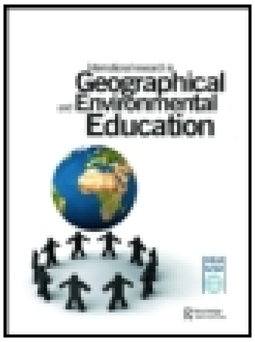

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Playing on reality: do geomodels improve the perception of geographical terms?

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ABSTRACT

Remodeling of geography education has been an ongoing challenge recently. Constructivist pedagogy, employing tools of problem and model-based learning, offers new opportunities to meet these challenges. Geomodels, flumes and stream tables may ease the understanding of geographic processes through hand-on-experience for students. With a computer-controlled geomodel, we analyzed the development of 36 high school students' terminology in the fields of potamology and remote sensing. Potamology terms, provided after the experimental session, were more focused and reflected the information perception and fixation during the experiment. Three weeks later the terminology of the students indicated a partial fixation of the relevant terms. When students' terminology on remote sensing was analyzed, the pre-experiment terms were loosely connected to the topic. Over the class, students' terminology increased in the field of potamology. Although it became more topic-specific and focused, students' remote sensing terminology still contained a large number of off-topic terms by the end of the experiment and three weeks later. Our findings revealed one of the major weaknesses of the Hungarian educational system, i.e. teachers are forced to follow the conventional geographical curricula, therefore hindering their adaptation to cutting-edge educational methods and the learning-by-doing approach of the Western European and North American syllabi.

KEYWORDS
Learning-by-doing; geomodel; problem-based learning; modeling

Introduction

Media provides ample information on disasters with catastrophic consequences that may occur across the globe. These catastrophes include, among others, earthquakes, landslides, debris avalanches, floods, flash floods, tsunamis and tornadoes. Research has soundly demonstrated the decreasing recurrence interval of these extreme physical phenomena and this statement is especially true for weather-related disasters. The increasing frequency of events of the latter type is likely due to human-induced climate change. The

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impacts of climate change are further exacerbated by global population growth, while, simultaneously, the increasing frequency of extremities also contributes to risks from associated physical processes. For future adaptation, the following research questions need to be answered: how accurately do we know the reasons for the emergence and generation of these catastrophic events? Is the society prepared for the prevention, or mitigation of unwanted phenomena? How can we extenuate the socioeconomical, or more generally, the environmental impacts of disasters? Physical models, like flumes and geomodels, may help to answer these questions and contribute to the better understanding of such physical processes. Although such tools are often available for research, with the exception of Western Europe and North America, they are almost completely unknown as educational aids, especially in the field of geography.

In constructivist pedagogy people develop their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences (Agnew, 2001). Implication of virtual words (e.g. Dittmer, 2010), infusion of digital technologies (Karolčík, Čipková, & Mázorová, 2016; Yeung, 2010), interactive multimedia programs (Maor, 2012), hand-on-experiences and learning-by-doing type geography teaching may provide adequate tools to increase the perception efficiency of sound scientific processes and course materials and to handle teaching challenges, when conventional teaching methods are barely efficient and knowledge becomes non-transferable (Felder & Silverman 1988; Le Heron, Baker, & McEwen, 2006). According to the principles of the constructivist pedagogy, human learning primarily depends on the construction and synthesis of knowledge, which is an individual implementation process in the mind of the learner and is built upon preexisting base knowledge (Maor, 2012). Existing mental map or global models in human mind accommodates new ideas uniquely and inserts them among the existing concepts. In other words, construction of new knowledge is based on the own unique structure of the individual's mind (Glasersfeld, 1991). Constructivist learning, however, requires a distinctive learning environment, where real, life-like problems are solved, and emphasis is placed on individual learning and problem-solving tasks. Model-aided learning often transformed into engagement in the subject of interest and generates an intrinsic motivation for learning (Smith, 2005). Nevertheless, instead of individual learning and performances, students may work in groups, which results in new forms of collaboration activities during which many new skills and competences may emerge (NSNJ, 2010).

Model experiments are one of the novel forms of problem-, research- and design-based learning (DBL) types, which is also apt for the principles of constructivist pedagogy (Vankan, 2003). Model and experiment-based learning is also one of the most suitable applications in constructivist pedagogy while, at the same time, it also includes a significant mental development potential for students (Oosta, De Vriesa, & Van der Scheeb, 2011).

Problem-based learning (PBL) is a unique teaching and learning approach (Albanese & Mitchell, 1993; Barrows & Tamblyn, 1980), or educational strategy, where real-life problems are solved by a small group of students, through the integration and synthesis of formerly acquired knowledge. Some authors (e.g. Allen, Duch, & Groh, 1996; Boud & Feletti, 1991, 1997; Boud, Cressey, & Docherty, 2006) claim that PBL approach is a distinctive type of curriculum development, where students are motivated by and confronted with real-life, practical problems. A special learning environment, in general, characterizes PBL, where the motivation force is the problem itself (Figure 1). A major benefit of

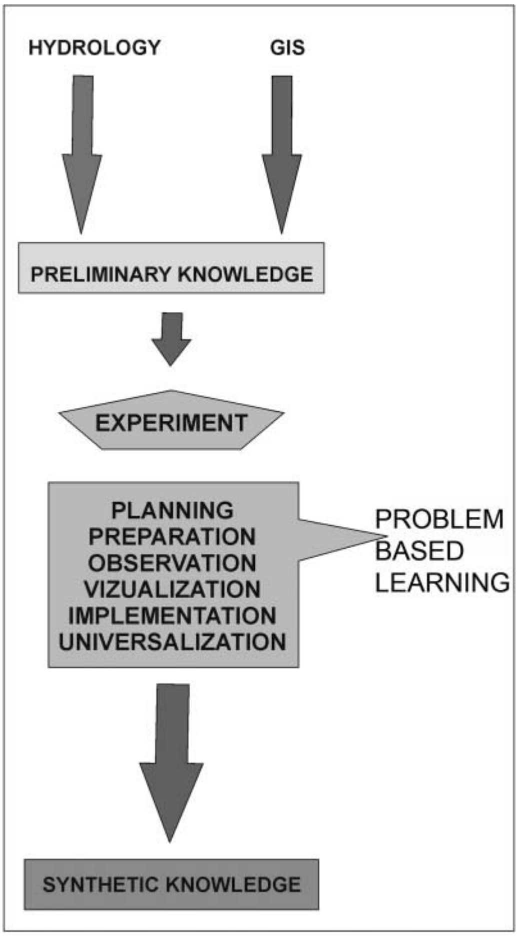

Figure 1. Simplified flowchart of the problem-based pedagogy in a specific experimental environment.

problem-focused learning is the development of the students' analytical skills and creative thinking (Arts, Gijselaers, & Segers, 2002). The efficiency of PBL learning types can be further increased by the incorporation of info-communication, near-remote sensing and multimedia systems. New achievements of information technology, including data identification and use of available data bases for problem-solving as well as Internet provided information are especially beneficial for PBL (Savery, 2006). To answer a problem, students may work in groups, though learning is also possible through individual research projects. In other words, during a PBL activity, cooperative learning, project work and research-based learning (RBL) can be mutually interlinked (Walton & Matthews, 1989). A second objective of PBL activities should increase students' awareness of different PBL methods in virtual space (Gibbings, Lidstone, & Bruce, 2008).

One of the major features of RBL is the instructor's facilitator function during the learning process. RBL is based on the interpretation of novel information that is acquired through the understanding of new material and is essentially a research-stimulated learning that is driven by questions and problems (Spronken-Smith, Angelo, Matthews, O'Steen, & Robertson, 2007; Spronken-Smith, Walker, Batchelor, O'Steen, & Angelo, 2011, 2012). In RBL, students experience the processes of knowledge acquisition and generation, while they untangle life-like and practical problems. As a result, students' problem-solving skills progress, their indigenous research expertise develops and following the RBL method students understand the essence of scientific cognition.

DBL or learning through design is a sub-category of RBL (Anderson, 2006). According to the main principle of DBL, students do not work with ready-to-use knowledge, but actively participate in planning and development of scientific model experiments. Learning-centered methods, practically implemented by constructivist pedagogy, are generally closely related to each other. An umbrella term for model-based learning methods is "inquiry-based-learning" (IBL) (Barron-Hammond, 2008; Watson, 2008). IBL, as being the most comprehensive or catch-all term, contains all the aforementioned teaching methods, complemented with the project method. In this approach, a project-centered system could be part of all teaching methods, and could provide a comprehensive framework for the realization and implementation of each learning and perception method, and may substantially contribute to successful exploratory learning (Schraw, Crippen, & Hartley, 2006).

We believe that constructivist pedagogy has published and delivered numerous learning-by-doing methods over the past decade. Their adaptation and employment have provided the elaboration of novel, discipline-specific learning management methodologies (Agnew, 2001). In the current paper we provide a case study of a learning-by-doing, PBL-type learning tool that, beyond the application of the elements of exploratory learning, introduces a geomodels, designed to visualize various physical processes in the field of geography. By applying and combining the aforementioned methods of constructivist pedagogy (PBL, RBL and IBL) we demonstrate the usability of learning-by-doing techniques in the Hungarian geography education and, similarly to formerly published papers in the field (Horváth & Probáld, 2003; Nemerkényi, 2003), reveal the major shortcomings of Hungarian geography education.

Experimental and research objectives of geomodels and stream tables

Geography is a synthetizing and multidisciplinary science: it analyzes the objects, processes and interconnectedness as a complex system, and is reflected to the environment in a comprehensive manner (Corrigan, Dillon, & Gunstone, 2011; Field, 2003; Healey, 2005). As physical models, geomodels, sand tables and flumes represent the complexity and the bridge between the computer-based numeric models and the full-scale processes (Bertalan, Tóth, Szabó, Nagy, Kuda, & Szabó, 2016; Norton, Ritchie, & Ginns, 2007). Consequently, geomodels are ideal and relatively novel tools, and if used appropriately, may contribute to the development of sound synthetizing knowledge.

Over the past decades, hydrometeorological monitoring has been launched in many instrumented catchments all over the world and numerous computer models have been elaborated for the explanation of some of the "eternal" questions of fluvial geomorphology that could contribute to the non-scientific understanding of these processes for non-professionals. At the same time, the weaknesses of the first (a labor and time-consuming activity involving high expenses) and the second approach (e.g. magnification of errors springing from incorrect parameterization or limited applicability to real-life situations) have also been recognized (Healey, Kneale, & Bradbeer, 2005).

Geomodels, in general, represent a multilateral research and educational approach by employing novel teaching methodologies to implement and analyze various environmental system processes (Healey & Jenkins, 2000). In the current paper, we discuss the educational benefits of using a computer-controlled geomodel (an experimental stream and tectonic table) as a teaching tool for introducing hydrologic, geomorphologic and tectonic dynamics to grammar school students (in Hungary this age group is aged between 12 and 18). The geomodel at the University of Pécs is used as an educational resource for grammar school students and primarily as a research tool for BSc, MSc and PhD courses to demonstrate the principal hydrologic, geomorphologic and geologic processes.

The overall educational objective of the geomodel demonstrations is the acquisition of essential water and floodplain controlling skills by students interested in water management and, with an increasing importance lately, to develop responsible environmental consciousness. The application of the experimental geomodel not only allows the students to experience the basic concepts of hydrology and hydraulics, but also to introduce surface dynamics in a hands-on manner. Students also acquire the relevant terminology and skills to control and model complex environmental processes. Students also take the necessary steps required to face any control system design processes, including controller design, system calibration and simulation, and analytical implementation and visualization of system processes in real time.

Observing scaling rules, small-scale physical models, long established in water engineering, seem to be capable to bridge the gap between the aforementioned two approaches. If the results of experimentations could be quantified, physical modeling may also be helpful for the theoretical foundation of various water management tasks (including dam constructions, designing flood control alert and warning systems or planning river rehabilitation). These management tasks are important issues of the society and similar topics abundant in media and, in general, in our everyday life. Nonetheless, physical modeling, and in general geomodels, are not only suitable for research purposes, but also represent an efficient teaching tool and an integral part of constructivist pedagogy.

The geomodel at University of Pécs (UP), and in general, all geomodels are suitable for the demonstration of selected natural processes that occur on a geologic time scale, i.e. takes an excessively long time. Other, short-term, but complex processes, like floods, dam breaches and landslides may induce profound economic and life losses. When employing a PBL-type approach, an undesired condition is generated or reconstructed in the geomodels, and the students are urged to come up with possible solution alternatives that are based on their existing knowledge. This approach assumes a preliminary perception in the field of geomorphology, hydrology and related geography topics. By employing the preliminary knowledge and the realization of the problem, the students mentally visualize and plan the experiment and the possible solution pathways.

From the viewpoint of teaching, the specific purposes of the project class were to:

(1) make students understand the natural flow mechanisms of streams and rivers (explain how streams shape the Earth's surface, erosion processes and accumulation) and interconnectedness within natural cycles and processes;
(2) introduce river-related terminology;
(3) provide a general overview of the development of stream and drainage network;

(4) to provide knowledge on the importance of remote sensing in environmental observations and analyses;
(5) to predict the future natural development of river networks without human interference;
(6) introduce environmentally safe and friendly hydrologic and geomorphologic terms related to watersheds and river geomorphology;
(7) increase the skills and competences on spatial orientation;
(8) introduce and emphasize the importance of remote sensing on decision-making and approaches to effectively manage river networks;
(9) provide examples for anthropogenic relationships in nature;
(10) change the conventional, static geographic education to a more dynamic approach that is based on visualization and direct interpretation.

Geomodels, sand tables and flumes were already employed as experimental tools by the Greeks. However, the tools of physical modeling have been neglected since the widespread use of computer-aided modeling techniques (e.g. animated visualization methods, video games and Google Earth) (Tüzüna, Yilmaz-Soylua, Karakuşb, Inalb, & Kizilkayaa, 2009). The theoretical background on water dynamics and control supporting is usually not included in most grammar school geographical curricula; thus, using geomodels as a teaching resource is a novel way of introducing future geographers and civil engineers to new technologies, bridging classroom and practical activities on model facilities. The experiments presented in this paper can be easily implemented in similar "hard science" disciplines that may complement conventional curricula.

The objective of the current paper was to evaluate how the PBL-type educational approach enhanced the students' knowledge, attitude and skills toward the fields of geographic processes during an experimental class. We investigated whether the applied method deepens the student's knowledge and changes their approach to information perception on remote sensing and potamology.

Methodology

Experimental set-up and specifics of the geomodel experiment

During the demonstration of a case study experiment at the Institute of Geography at the University of Pécs, Hungary, experiments were carried out in the geomodel described above. The geomodel table was filled with 1000 kg of modeling media that consisted of bentonite clay and sand particles of three different mean particle diameter (2 to 1, 1 to 0.5 and 0.5 to 0.1 mm). The mass ratio of each of the four modeling media types was 25%. Tap water was entered onto the media at the upper end of the geomodels. Water flowed from a 1 m^3 plastic container through a hosepipe and a 2-L glass beaker to maintain constant hydraulic pressure.

Two different types of geomodel experiments were carried out with the active participation of 36 grammar school students representing the Babits Mihály High School of Pécs (students were aged 15–16). The first experiment focused on the formation of a natural channel network. The second experiment targeted the development of a river delta. These two experiments also involved the representation of remote sensing and Geographic Information System (GIS) mechanisms.

Channel formation

Over the course of the first experiment, we demonstrated how natural meandering and braided river channels are formed on an initially plain surface tilted at an angle of 4°. The initial condition was a straight, V-shaped streambed of about 5 cm depth and 5 cm width at the top. Water was introduced from a hosepipe through a 2-L beaker at a constant pressure at a flow value of 5 L per minute. Surface of the flume media was pre-wetted to a volumetric water content of 0.3 m^3/m^3 with a sprinkler to speed up channel formation processes in a timely manner. The lower 1.2 m of the geomodel was not filled with modeling media in order to allocate space for delta formation. The experiment was run for 1 h and 20 min. When delta development began, the geomodel vessel was tilted to the left and then to the right at an angle of 2.5° (two times in each direction) to initiate bird-foot delta development.

Students' questionnaire survey and terminology assessment

To evaluate the progress of the students' terminology on the relevant hydrologic (potamology) and remote sensing terms and in general their physical geographical knowledge students' terminology was assessed at three different times on potamology and remote sensing: (1) prior to class (PC survey), (2) right after class (RAC survey) and (3) three weeks after class (3WAC survey). The list of the provided terms by the students was subsequently compared with the terms listed in grade 9 Hungarian state text books and the diversity and the development of their terminology were analyzed for the three surveys.

Students were provided with images of meandering and braided channel reaches with which they had to match the observed geomorphological features. To improve the students' hydrological terminology, basic hydrologic terms were briefly explained by the moderator (Figure 2).

Results and experimental outcome

To evaluate the efficiency of the PBL-type learning, we assessed 36 students' initial knowledge in the fields of potamology and remote sensing. The total number of terms associated with potamology and remote sensing topics were evaluated three times, to assess pre-experiment knowledge, student perception, imprinting and motivation for the geography-related topics.

Change of the potamology terminology of the students

In the first questionnaire, prior to the demonstrational class, the majority of the students answered the river hydrology terms in an ad hoc manner, however, words, not directly associated with hydrology, were also commonly listed (Figure 3). Three terms, "river", "water" and "flood" were listed in both the pre- and post-class survey (Figure 3(a,b)). Interestingly, the term "river" was ranked at second place in both cases. In contrary, the term "watershed" did not enter to the top 10 after the lab session even though the experiment intended to model watershed-scale hydrologic processes. Terms, provided after the experimental session were *more clear-out, focused and concentrated on potamology* and reflected the information perceived during the experimental session. The reason for the

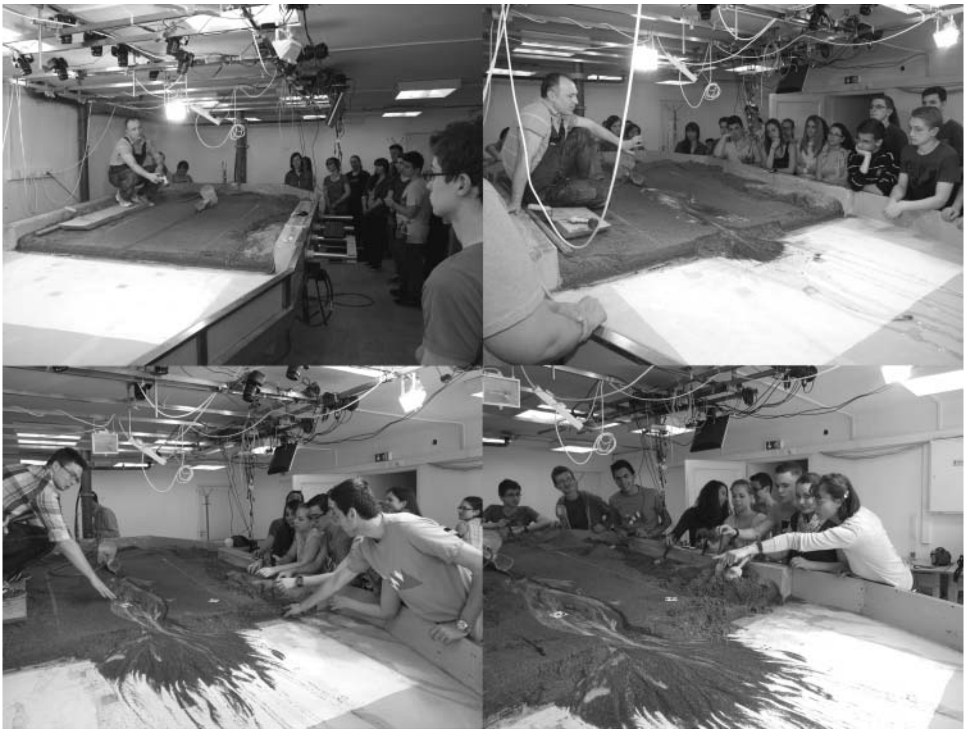

Figure 2. Students involved in the individual phases of the geomodel experimental session at UP.

non-exact interpretation and use of hydrologic, and hydrology-associated words likely originated from the definition-centric and theory-based educational approach in Hungary. Furthermore, most teaching methods in Hungary do not aim at transferring the use of acquired terms into novel contexts and do not condition students for the direct association of formerly learned terms.

Interestingly, for the 3WAC survey the terminology of the students was rather similar to that surveyed during RAC (Figure 3(c)), *indicating a strong perception and the subsequent fixation* and evocation of the relevant hydrologic terms. In addition, the largest number of terms was found for the 3WAC survey, although differences were relatively minor when the results of the three assessment sessions are compared (Figure 3(d)). This is likely caused by the discussion on potamology and river hydrology during the students' subsequent geography classes, and, in case of some students, on their increased motivation in the fields of hydrology and geography.

The flume experiment relied on the students' preexisting knowledge on river hydrology and transport capacities. This topic was taught exactly four weeks before the experimental lab session for the tested students. The diffuse terms associated with the topic dramatically changed by the end of the experimental class. All terms, listed at the end of class, were closely related to the topic of potamology. Therefore, our preconception, i.e. the more explicit perception of associated terms due to the practical viewpoint and placement in contexts and nexus, was corroborated. However, our second hypothesis, the long-term fixation of the newly acquired terms was only partially proven this way, as students provided somewhat different terms for the 3WAC survey.

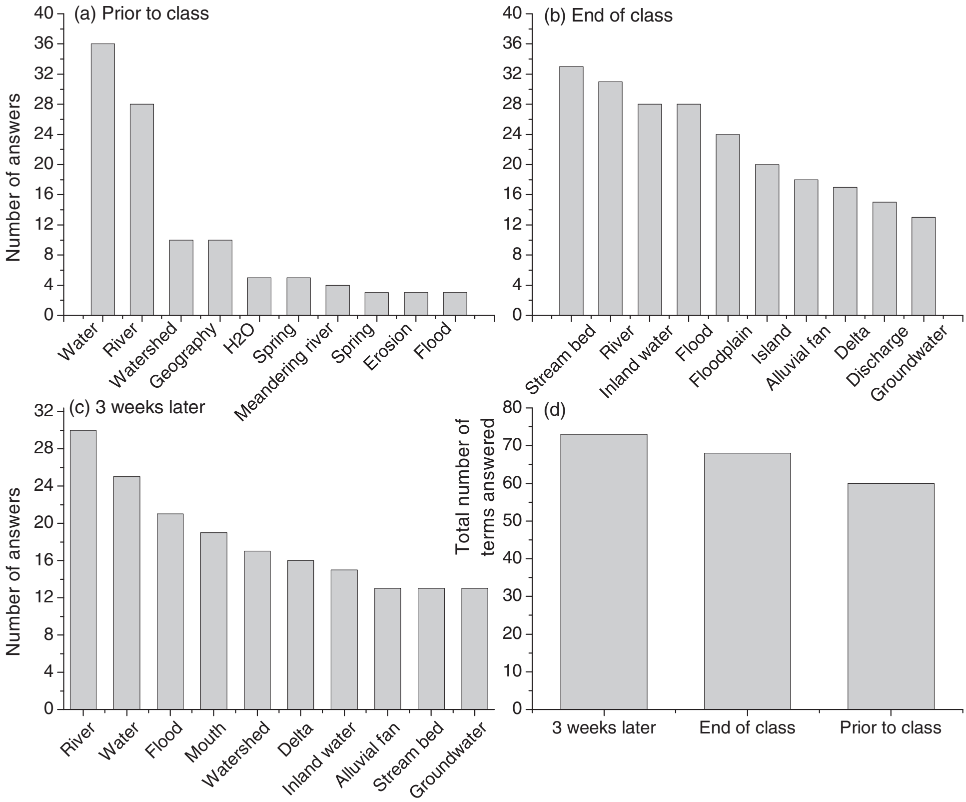

Figure 3. Number of top 10 answers for river hydrology terms prior (a), immediately after (b) and three weeks after class (c) and the total number of terms answered during each survey (d).

Change of the remote sensing terminology of the students

The list of the terms provided in the field of remote sensing showed a very different picture compared to the field of potamology (Figure 4). When we assessed the students' terminology on remote sensing, the total number of terms provided decreased from 83 prior to class to 77 after class, while a more significant decrease was observed three weeks later, when only 36 terms were given. *The pre-experiment terms were more diverse than the list of the hydrology terms and were loosely connected to the topic of remote sensing.* This diversity was indicated by the large number of different and off-topic answers prior to class (Figure 4(d)). A large number of words were irrelevant for the topic of remote sensing, as terms, more closely associated with astronomy, like planets, Earth, Mars and soil were also included in the list provided by the students. Even though the students have already encountered the term satellite in their geography textbook four weeks earlier, and the term itself is part of the Hungarian geography curriculum, it did not make it to the top 10 answers prior to the lab session (Figure 4(a)). The 9th-grade geography textbook contains only two terms in the field of remote sensing (satellite and remote sensing), still the students demonstrated a detectable lack of deep understanding of remote sensing as an analytical procedure.

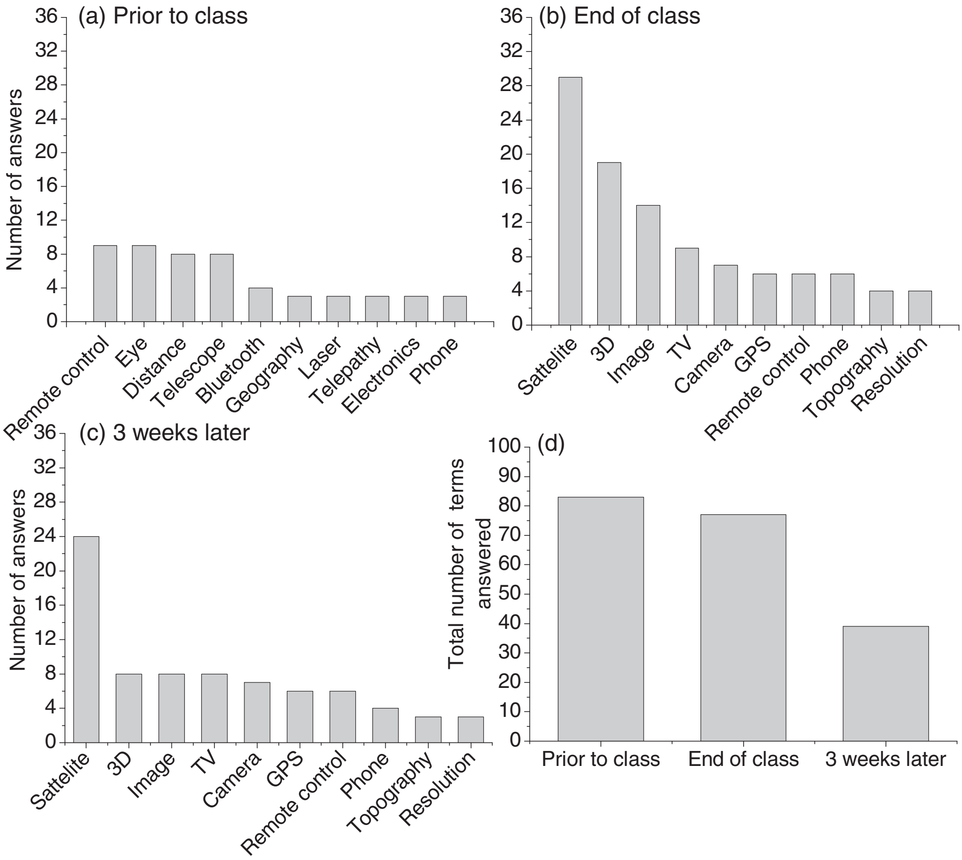

Figure 4. Number of top 10 answers for remote sensing terms prior (a), immediately after (b) and three weeks after (c) the lab session and the total number of terms answered during each survey (d).

Although students' terminology became more focused by the end of the experimental class and three weeks later, it still contained a large number of off-topic terms, like TV and remote control. However, the term "satellite", unlisted prior to class by the students, was ranked first place for both the RAC and 3WAC surveys. Even though similar terms were included in the top 10 list right after and three weeks after class distribution of the terms, the shape of the two histograms was markedly different (compare Figure 4(b) and (c)). Another interesting aspect of the remote sensing survey is the ranking of the term "GPS". This term was absent for the PC survey, was ranked in the sixth place in the RAC survey, while was the second term listed in the 3WAC survey. This change of ranking likely indicates motivated learning by the students, as a result of the learning-by-doing educational approach.

Patterns of the total number of answers given for the potamology and remote sensing terminology surveys

When the total number of answers were compared for the three surveyed times in the fields of potamology and remote sensing, different patterns were observed. The total

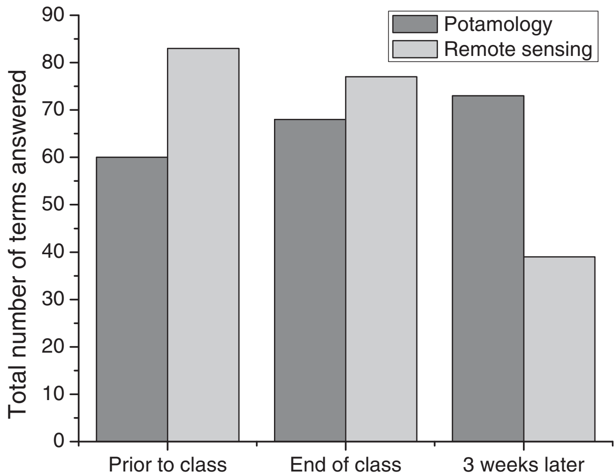

Figure 5. Changes of answers provided prior, right after and three weeks after the experimental class in the fields of potamology and remote sensing.

number of answers gradually increased with time regarding the students' terminology in the field of hydrology. This is likely explained by three factors. First, some students became strongly motivated by the experience-based learning approach and the use of the geomodels as a teaching aid. Second, due to Hungary's lowland position, water is a frequently returning topic in Hungarian media, especially during rainy periods, when floods and excess water often appear in the news and other media types. Third, for some students the hand-on-experience with the UP geomodels enhanced the long-term perception and imprinting of relevant hydrologic terms. In addition, the development of students' terminology in remote sensing indicated a more cleared-out, focused and topic-associated list of terms with time, indicating the more profound understanding of the topic due to the hand-on-experience class.

Nonetheless, the temporal behavior of the total number of remote sensing showed a very different picture from that of the potamology. For the remote sensing terms, the total numbers of answers decreased with time, likely indicating the gradual understanding the role of remote sensing and the gaining understanding on the process of remote sensing. Even though remote sensing is a more specific topic than the broader hydrology, the total numbers of answers given were almost identical to the number of potamology terms (Figure 5). Also, the word "satellite" indicated a strong imprinting in students. Although the topic itself is part of the curricula and the word explicitly appears in the official text book, students could not associate the term with remote sensing (see Figure 3(a)).

Conclusions

In the current research, with three questionnaire-based surveys, we reported the usability of geomodels on easing the perception of hydrologic terms for 9th-grade grammar school students in Hungary. The analyses of the questionnaires showed that the students' terminology could be improved by using systematic model-based diversification and selection of downscaling methods to interpret physical processes. By working on natural riverbed and alluvial fan formation with the geomodel, student familiarized themselves with a state-of-the art geomodels at UP. Based on these experiments, students gained skills on recognizing similar morphologic and hydrologic processes in other geographic environments, i.e. *acquired skills on abstract interpretation*. The currently presented learning-by-doing approach may help to motivate students in the fields of hydrology, remote sensing and physical geography, while in general, it contributes to the sound understanding of natural phenomena. The use of visualization tools, such as the currently presented geomodels, may boost the students' self-development trajectories while teaching approaches of these types should be added to conventional and quasi-conventional teaching curricula. Our results therefore corroborate previous findings (e.g. Reinfried, 2004) and, in addition, point out the need for innovative and cutting-edge topics, like remote sensing should be introduced to geography syllabi. Due to the synthetizing approach of PBL in both theory and practice, students will be capable of abstract thinking and multi-criteria decision-making as well as solution of complex and challenging problems if input knowledge is presented in a more visualized and entertaining way.

The perception and the subsequent evocation of terms on physical processes could be placed into a new context with the use of visualization tools, like sand tables, flumes and geomodels. Therefore, geomodels introduce a novel teaching application into geography education, where the tradition is the reproduction and remodeling of natural processes. The application of geomodels during the presented experiment also increased the student's motivation, since the majority of students remained in the laboratory after class and showed a keen interest to the geomodels. Such motivation is rarely observed during conventional geography classes in elementary and high schools. Unfortunately, due to the rigid and non-flexible class syllabi in Hungary, there is a very limited potential for the introduction of hand-on-experience classes and PBL-type learning as well state-of-the-art topics like remote sensing. This way, our findings revealed one of the major weaknesses of the Hungarian educational system, i.e. teachers are forced to strictly follow geography curricula, thus hindering their adaptation to alternate educational methods and to learning-by-doing approach of Western European, North American or Australian teaching policies (see e.g. Casinder, 2016; Reinfried, 2004).

The need for more hand-on experiences is also validated by the students. Based on the informal communication with the students after the experimental class, classes should be engaged more frequently in the form of doing-by-learning education. Reflective thinking, atypical in Hungarian education, should be propagated and emphasized among students. According to our surveys prior and after the demonstrational class, an apparent gap is observed between students' theoretical perception and practical hand-on experiences.

The geomodel-aided class not only discovered the misconception of selected terms (similarly to the findings of, e.g. Chang & Pascua 2016; Reinfried, 2006; Trend, 2001), but also the incorporation of relevant terms at a high degree of internal consistency and concentration for the studied group of students. The employed educational environment revealed differences between the ways in which students perceive new information. Findings of the current research were consistent with past research (e.g. Maor & Fraser, 2005), i.e. learning-by-doing teaching practices and model-aided learning and synthesis enhance the perception efficiency of students in the field of science, technology, engineering and mathematics (STEM). In accordance with the findings of McDougall and Squires (1997) and Tani (2004), this suggests a need on shifting pedagogical practices and focuses from theory and frontal teaching to learning-by-doing techniques and giving increased focus to experiments both in and outside classrooms.

The current outcomes might be inspiring, but they also encourage us to reflect critically on our pedagogical framework and the implementation of learning-by-doing techniques during the teaching of STEM topics (Reinfried, 2006). Although we are stimulating a highly constructivist learning environment by increasing opportunities of the learning-by-doing education methods and reflective thinking, promotion of hand-on-experience methods is essential for higher level learning. In conclusion, the findings of the demonstrational class with the geomodel at UP suggest the need for the development of learning-by-doing type learning environments. Students' expectations and their perceptions have pointed consistently to a need for further improvement. In particular, improvement of the technical aspects of the learning environment likely stimulates students to be engaged in higher order thinking skills and become more reflective learners. The results of the questionnaire-based survey of the current study, in accordance with the findings of previous studies (e.g. Maor & Fraser, 2005; Pirkhoffer et al., 2014), signpost new challenges in STEM education. This challenge for teachers is reflected in the need for the development of new learning environments by using demonstrational tools (Jonassen & Reeves, 1996) and by combining them with multimedia tools and providing opportunities for critical thinking and higher order learning (Garbinger, 1996).

Acknowledgment

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Disclosure statement

No potential conflict of interest was reported by the authors.

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