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LEARNING STYLE AS A FACTOR INFLUENCING THE EFFECTIVENESS OF THE INQUIRY-BASED SCIENCE EDUCATION AT LOWER SECONDARY SCHOOLS

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Abstract. *The IBSE has become a rather frequently applied strategy of directing learning activities in teaching science subjects. However, results of the IBSE effectiveness are not clear. A more detailed analysis is required which will reflect learners´ individual characteristics. Therefore, the main aim of this research is to discover what the effectiveness of IBSE reflecting individual learning style is. The learning style categorization followed the Honey and Mumford´s variation on the Kolb´s system. The IBSE effectiveness was detected by the didactic test consisting of 15 PISA-style tasks. The research was conducted in the sample of 332 learners who were exposed to IBSE for five months. Their knowledge was tested before, immediately after and four months after the IBSE approach was applied in lessons. The collected data were processed by ANOVA and Tukey HSD test. The results show that the highest short-term results were reached with learners preferring concrete sensing; the highest long-term results were reached with those of active processing of information. This finding might be caused by better use of metacognition and acquiring such individual metacognitive strategies which learners apply at utilization of information. Further on, the IBSE should focus on mechanisms of fixing the acquired knowledge.*

Key words: *inquiry-based science education, learning styles, educational practice, quantitative research, identification of learning results.*

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Introduction

Within the previous 10 – 20 years numerous studies on the IBSE effectiveness have been published. Selected texts from the 1996 – 2006 period were included in the review study by Furtak, Seidel, Iverson, Briggs (2012); latest works were summarized by Lazonder, Harmsen (2016). Various correlates of the IBSE effectiveness were researched in the above mentioned works, and the experimental, resp. quasi-experimental feature was detected as the common characteristics. Most of them were neither systemic, nor long-time studies. However, full answers to the questions on IBSE implementation can only be discovered within the long-time application of this approach which will not be limited to specific and (in essence) isolated learning contents but which will focus on the development of learners´ general competences targeting at the application of inquiry-based strategies of problem solving and self-directing and auto-didactic abilities (comp. Lamanauskas, 2012). Learners´ competences closely relate to their learning styles. The learning style is understood as a peculiar process of learning preferred by the learner in a certain period which has a character of a learning meta-strategy. As such, the learning style is a crucial feature of learner´s individuality. The impact of selected characteristics of single learners on the IBSE results has been proved, e.g. the work (Škoda, Doulík, Bílek, Šimonová, 2015) deals with learner´s type of motivation on the effectiveness of IBSE. Learning styles are expected to provide even stronger impact, as they arise from a preferred type of mind processes which can be compatible to those applied in IBSE. This expectation was verified within the process of long-time experimental teaching applying the IBSE approach in science subjects in the sample group of 15-year old Czech learners of different learning styles (Honey and Mumford´s variation on the Kolb´s system).

Theoretical Background

The learning style can be understood as a relatively stable set of activities based on a certain inborn cognitive style, on a way of processing information, which can be at the same time changed under the influence of education and self-education in the wider context. It does not cover learning skills, experience and abilities only but it also includes attitudes and inner motives to learning and inherited pre-dispositions to cognition and learning (Boyatzis, Kolb, 1991). The learning style embraces numerous mutually conditioned components: cognitive, motivation, emotional and social components, the impact of inner and outer conditions, self-direction of own learning (Cassidy, 2004). The Curry´s onion model of learning style (Curry, 1987) clearly displays the principle. The deepest layer, i.e. the inborn basis, particularly the individual´s cognitive style, is the most stable and least open to changes initiated by the outer impact. The middle layer, which includes the information processing and probably arises from the inborn background, can be partly changed by outer interventions (e.g. the learner is encouraged to process and acquire the learning contents). And, another middle layer, embracing social and motivation processes, can be also partly impacted (by the teachers and parents acting, learner´s life experience etc.). The outer layer, relating to pupil´s learning preferences (i.e. the preferred learning strategies, teaching methods, organizational forms etc.), can be influenced by the way of conducting the process of teaching. Moreover, the layers are not strictly separated but they mutually penetrate and work as a whole, a complex of several components.

There exist numerous learning style models (e.g. in Casidy, 2004). This research was based on the Kolb´s model of learning styles which arises from his learning theory. The Kolb´s model is sophisticated, since it offers both a way to understand individual people´s different learning styles and an explanation of a cycle of experiential learning. Kolb´s learning theory sets out four distinct learning styles (preferences) which are based on a four-stage learning cycle. Kolb includes this "cycle of learning" as a central principle of his experiential learning theory, typically expressed as the four-stage cycle of learning, in which "immediate or concrete experiences" provide a basis for "observations and reflections". These "observations and reflections" are assimilated and distilled into "abstract concepts" producing new implications for action which can be "actively tested" in turn creating new experiences (Kolb, 1984). In ideal case this model represents the "cycle of learning"; changes in learning style reflecting the pupil´s age are derived from this cycle. The Kolb´s model works on two levels: (1) a four-stage cycle which includes

- Concrete Experience - (CE)
- Reflective Observation - (RO)
- Abstract Conceptualization - (AC)
- Active Experimentation - (AE)

and (2) a four-type definition of learning styles, each representing the combination of two preferred styles, rather like a two-by-two matrix of the four-stage cycle styles, as illustrated below. Kolb uses following descriptions of styles:

- Diverging (CE/RO)
- Assimilating (AC/RO)
- Converging (AC/AE)
- Accommodating (CE/AE).

For the research purposes, it is more appropriate to apply the modified model by Honey-Mumford which is based on the Kolb´s learning cycle (Honey, Mumford, 1992). This model distinguishes four learning styles which are reflected in the Kolb´s four-stage model as follows:

- Activist = Accommodating style. Prefers the challenges of new experiences, involvement with others, assimilation and role-playing. Likes anything new, problem solving, and small group discussions.
- Reflector = Diverging style. Prefers learning from activities that allow watching, thinking and reviewing (time to think things over) what has happened. Likes to use journals and brainstorming. Lectures are helpful if they provide expert explanations and analyses.
- Theorist = Assimilating style. Prefers thinking about problems through in a step-by-step manner. Likes lectures, analogies, systems, case studies, models and readings. Talking with experts is not helpful.
- Pragmatist = Converging style. Prefers applying new knowledge to actual practice to see if they work. Likes laboratories, field work, and observations. Likes feedback, coaching and obvious links between the task-on-hand and a problem.

Researches in the Field of Learning Styles and IBSE

The IBSE has been a subject of research for more than 30 years. Most studies focus on the impact of IBSE on the results of instruction with learners of various age groups compared to the traditional (i.e. non-IBSE) approaches. Less attention is paid to other intervening variables, particularly individual characteristics of learners. In the previous research (Škoda, Doulík, Bílek, Šimonová, 2015) the impact of different motivation types of learners on the IBSE results was proved. Within the complex evaluation of IBSE results individual learner´s differences should be reflected; the learning style is one of them.

Results of the below presented studies support our expectation that the IBSE effectiveness is influenced by the learners´ styles and the way how teachers reflect them in designing concrete learning strategies and methods. One of the studies explicitly dealing with learning styles was published by Hsiao-Lin Tuan, Chi-Chin Chin, Chi-Chung Tsai, Su-Fey Cheng (2005). Authors monitored differences in the effectiveness of the inquiry-based science education with learners of different learning styles exploiting the Learning Preference Questionnaire. They discovered that no statistically significant differences were detected for particular learning styles in the inquiry-based science education between the experimental and control groups. Another study was published by Brown, Melear (2006) who focused on teacher´s style of instruction, particularly teacher´s strategies of directing pupils´ learning activities in the inquiry-based science education emphasizing teacher´s and learners´ activity. Both approaches proved to be effective. Nevertheless, the observations within the study showed that half of the teachers who proclaimed the emphasis on activity in the interview with the researchers applied different (non-active) approach in the lessons and provided more space for learners´ activity, which is a necessary feature of IBSE. In some other studies more attention is aimed to the process of directing pupils´ learning activities than to their learning styles and preferences. These studies mostly come under the subject didactics (e.g. Spronken-Smith et al, 2008; Parr, Edwards, 2004; Gwo-Jen Hwang, Li-Yu Chiu, Chih-Hung Chen, 2015). Not the pupil´s learning style but the effectiveness of IBSE is in the centre of interest there; however, learning styles were mentioned, reflected or considered. The directing of pupils´ learning activities (despite it definitely belongs to the teacher´s educational activities) is adjusted to pupils´ learning styles, e.g. within the collaborative learning, selecting the appropriate didactic means or applying specific communication patterns. Moreover, in subject didactics learning styles are considered, reflecting the type of provided information (visual, auditory, kinaesthetic learning styles). This rather outmoded classification arises from the Dunn and Dunn concept (1978) but it was widely exploited in subject didactics (e.g. Gilakjani, Branch, 2012). It particularly determines ways of providing new information in lessons, when presentations, smartboards, animations, visualizations are used, mind maps created and practical activities conducted. However, this concept of pupils´ learning styles and their implementation into instruction is implicit only. The teacher is aware of pupils´ learning styles, works to meet them but does not accommodate them intentionally.

Rather different results of studies and researches on the IBSE effectiveness indicate that this phenomenon should be researched in detail and permanent attention should be paid to various intervening variables. As arising from learners´ individual characteristics, they are important correlates of the effectiveness in any educational process. A certain sequence of mind operations based on the Foragigng Process Skills (Pirolli, Card, 1999) is a characteristic feature of IBSE. It includes observation, conducting measurements, deriving, predicting, setting and/or verifying hypotheses. This process is more appreciated by the learners preferring concrete sensing and inductive thinking. The traditional behavioural model of teaching arises from Exploiting Process Skills (e.g. Rosebery, Puttick, 1998) which uses classification and organizing of data, defining models, identifying cause – effects relations, identification and characterizing of variables. These processes are preferred by abstract-sensing and deductive-thinking learners. Despite learners should be able to apply various mind processes to various educational situations, some of the situations (and related strategies directing learning activities) are preferred, and the others are not. Reflecting all the above mentioned, the main research problem solved in this study is how the preferred mind processes reflected in individual learning styles impact the IBSE results from the short-term and long-term view.

Methodology of Research

General Background of Research

The conducted research was based on the systemic five-month application of IBSE in science lessons of Czech 15-year old learners. Reflecting the research problem within this research, following main question was set: Is there any correlation between the learning style and the effectiveness of IBSE? Consequently, the main research aim is to discover whether there exist any correlations between the four types of learning styles and the effectiveness of IBSE.

Main research aim was structured into following objectives:

1. To detect individual learning styles in the research sample by applying the Honey and Mumford's variation on the Kolb´s system. Results are structured according to the strongest learning style.
2. To identify learners´ starting level of science knowledge (expressed in pre-test score) before the IBSE is applied. Learners´ knowledge was detected from previous formal, non-formal and/or informal education, media, peers etc.; it was understood as learners´ preconcepts.
3. To identify learners´ knowledge (expressed in post-test1 score) after the five-month application of IBSE approach.
4. To identify learners´ knowledge (expressed in post-test2 score) after another four-month period after the application of IBSE approach was finished.
5. To discover differences in learner´s knowledge (expressed in post-test1 and post-test2 scores) in single groups of learning styles.

To answer the research questions, six hypotheses were set. Reflecting the fact that the multiple comparison of selected parameters was conducted, the following null hypotheses were defined:

H_{01}: Pre-test scores of learners in four groups of different learning styles do not differ.

H_{02}: Post-test1 scores of learners in four groups of different learning styles do not differ.

H_{03}: Post-test2 (retention test) scores of learners in four groups of different learning styles do not differ.

H_{04}: Differences in pre-test and post-test1 scores of learners in four groups of different learning styles do not differ.

H_{05}: Differences in post-test1 and post-test2 scores of learners in four groups of different learning styles do not differ.

H_{06}: Differences in pre-test and post-test2 scores of learners in four groups of different learning styles do not differ.

Sample of Research

The choice of the research sample was conducted on the intentional basis. It was determined by two main facts: (1) only such classes were included in the sample the teachers of which attended and finished the course focused on IBSE implementation into science education (15 teachers; 15 classes); (2) the classes were not specialized in other subjects (e.g. foreign languages, sports etc.). Total amount of learners included in the research was 339, i.e. these learners participated in pre-test, post-test1 and post-test2. If missing from any part of testing, they were excluded from the research sample so as the results were not influenced by this fact. After the test of learning styles was applied, seven learners of the indifferent learning style (i.e. those who could not be included in any of the four groups determined by the research instrument – see below) were also excluded from the research sample. Finally, data of 332 learners were statistically analysed.

Research Methods, Procedures and Instruments

The quantitative research design on the basis of quasi-experiment was applied for reaching the main research aim. Fifteen classes were intentionally selected where the IBSE approach was applied in teaching science subjects for five months. The research design, i.e. pre-test, instruction, post-test1, was conducted with the 8th grade learners, the post-test2 was applied with 9th grade learners of lower secondary schools (in cities and towns, not in rural areas) in the Czech Republic, one class per one school. The research was held in classes where learners´ parents were informed about the goal, process and intentions of the research, and expressed permission for conducting it by signing the written parental informed consent. The research was also approved by the Ethics board of the Jan Evangelista Purkyne University (UJEP).

The lessons were led by teachers – graduates of the course focused on the IBSE implementation (12 women, 3 men, having average teaching practice of 12.9 years). The quasi-experiment was conducted from December 2013 to October 2014, the IBSE approach was applied from January to May 2014. Participating classes were to meet the following conditions:

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- appropriate material equipment enabling to apply the IBSE approach in science subjects,
- science teacher of a five-year practice as minimum and trained in the IBSE course,
- school curriculum enabling the IBSE application,
- support and approval by the school management for running the quasi-experiment,
- no specialized classes and schools (i.e. in mathematics, foreign languages etc.) were intentionally included in the study, as this factor might have impact on the results and decrease the validity of the research.

The learning contents of the experimental group (where the IBSE was applied) and control group (where the IBSE was not applied) were identical. However, the groups differed in the manner how pupils´ learning activities were directed. The traditional (i.e. non-IBSE) instruction in the control group was conducted in the transmissive-instructive way using the verbal monologue and demonstrative methods of teaching. If experiments were implemented into the teaching process, they were of supportive and verifying character, and textbooks were used as supportive didactic means. The IBSE approach was based on constructivist paradigm directing learning activities towards solving the problem. The problem was determined by e.g. an experiment, nature process or phenomenon, demonstration of a physical laws or mind experiment. Further on, the process of instruction applied elements of individual and social constructivism: observation, observation analysis, comparison, discussion, information synthesis, generalization, construct application and construct verification. This procedure was modified in relation to the learning content of a concrete lesson, e.g. in mind experiments the observation and observation analysis were not used etc. Learners exploited worksheets prepared by the teacher before the lesson. The construct verification was conducted through verifying experiments, solving tasks or explaining phenomena known to learners from everyday life.

The total validity of the research was given by the facts that intentional research sample was exploited, determined by the person of the teacher trained in IBSE, so the results can be generalized to a limited extent. Exploiting the identical learning content the research could be easily reproduced.

Two research instruments were exploited to reach the research aim: Honey and Mumford´s Learning Styles Questionnaire and the didactic test.

Honey and Mumford´s Learning Styles Questionnaire (LSQ) arises from the original Kolb´s Learning Style Inventory (LSI) (Kolb, 1976). Compared to LSI, the LSQ is easier, thus enabling the application in the age group of 15-year learners. It consists of 80 statements. If the respondent agrees to some extent with the statement, s/he makes a tick. Each statement is typical for a certain learning style (activist, theorist, reflector, pragmatist). Finally, ticks are counted for each learning style. It is quite common that one learning style prevails with each respondent having more ticks than others. Then, the learner is classified under this group. If none of the learning styles prevail, the respondent is included in the group of indifferent style learners. Their learning style has not been completely profiled and cannot be distinguished in detail by this instrument.

Brief characteristics of single learning styles defined by Honey and Mumford follow (Honey, Mumford, 2000):

- Activists involve themselves fully and without bias in new experience. They enjoy the here and now and are happy to be dominated by immediate experience. They are open-minded, not sceptical, and this tends to make them enthusiastic about anything new. Their philosophy is: "I´ll try anything once". They tend to act first and consider the consequences afterwards. Their days are filled with activity. They tackle problems by brainstorming. As soon as the excitement from one activity dies down they are busy looking for the next. They tend to thrive on the challenge of new experiences but are bored with implementation and longer-term consolidation. They are gregarious people constantly involving themselves with others but in doing so, they seek to centre all activities on themselves.
- Reflectors like to stand back to ponder experience and observe them from many different perspectives. They collect data, both first hand and from others, and prefer to think about it thoroughly before coming to any conclusion. The thorough collection and analysis of data about experiences and events is what counts so they tend to postpone reaching definitive conclusions for as long as possible. Their philosophy is to be cautious. They are thoughtful people who like to consider all possible angles and implications before making a move. They prefer to take a back seat in meetings and discussions. They enjoy observing other people in action. They listen to others and get the drift of the discussion before making their own points. They tend to adopt a low profile and have a slightly distant, tolerant unruffled air about them. When they act it is part of a wide picture which includes the past as well as the present and others´ observations as well as their own.
- Theorists adapt and integrate observations into complex but logically sound theories. They think problems through in a vertical, step-by-step logical way. They assimilate disparate facts into coherent

theories. They tend to be perfectionists who will not rest easy until things are tidy and fit into a rational scheme. They like to analyse and synthesize. They are keen on basic assumptions, principles, theories models and systems thinking. Their philosophy prizes rationality and logic. "If it´s logical, it´s good". The questions they frequently ask are: "Does it make sense?", "How does this fit with that?", "What are the basic assumptions?" They tend to be detached, analytical and dedicated to rational objectivity rather than anything subjective or ambiguous. Their approach to problems is consistently logical. This is their "mental set" and they rigidly reject anything that does not fit with it. They prefer to maximize certainty and feel uncomfortable with subjective judgments, lateral thinking and anything flippant.

- Pragmatists are keen on trying out ideas, theories and techniques to see if they work in practice. They positively search out new ideas and take the first opportunity to experiment with applications. They are the sorts of people who return from management courses brimming with new ideas that they want to try out in practice. They like to get on with things and act quickly and confidently on ideas that attract them. They tend to be impatient with ruminating and open-ended discussions. They are essentially practical, down to earth pile who like making practical decisions and solving problems. They respond to problems and opportunities "as a challenge". Their philosophy is: "There is always a better way" and "if it works it´s correct".

The didactic test included 15 tasks built according to the PISA style towards testing science literacy. Ten tasks were convergent and five divergent ones. Pre-defined and strictly correct answer was required to the convergent tasks, totally providing 30 points. In divergent tasks learners designed a process of solution (e.g. how to separate components from a compound, to verify the impact of various factors on growth of plants etc.), whereas several solutions were correct. The maximum score was 25; total score of the didactic test was 55 points. The didactic test was piloted and optimized on the sample of 26 fifteen-year-old learners. The didactic test was first applied as pre-test in December 2013 before the quasi-experiment started. Second, it was used as post-test1 in June 2014; third, as post-test2 in October 2014. Then, the results were statistically processed from the point of success in task solving (i.e. test scores) in relation to the learning style. The reliability of the research instrument was calculated from the post-test scores, separately for convergent and divergent tasks. In convergent tasks the Cronbach's alpha = 0.847, in divergent tasks Cronbach's alpha = 0.729. Lower value with divergent tasks resulted from their higher heterogeneity, higher test score and the fact that fewer amount of them was included in the didactic test. However, both values of Cronbach's alpha are acceptable. The validity of test tasks is determined by the fact they were designed according to the PISA tasks which are exploited worldwide for the given age group of 15-year old learners.

Data Analysis

First, the individual learning styles were detected. Considering the strongest learning style learners were divided into four groups (Table 1). Then, for each group a matrix of results of didactic tests (pre-test, post-test1, post-test2) was created, and basic descriptive characteristics of single sets of data were set. Marginal results were not excluded, as they had been neither random results, nor statistical errors but they reflected learners´ real knowledge.

Data were tested by ANOVA (variance analysis). If the analysis rejects the global null hypothesis, i.e. if the observed value of significance level p-value < 0.05, ANOVA is supported by post-hoc statistical methods focused on detecting differences by multiple comparative tests. These provide information about the statistical significance of single differences in mean values of all possible pairs of compared groups. For the purpose of data analysis the conservative Tukey-HSD (Honestly Significant Difference) test was applied. It makes appropriate decisions on lower significance level, thus eliminating dangerous increase of type I error α, which is characteristic for more liberal tests, e.g. Fisher´s LSD (Least Significant Difference) test. All statistical analyses were conducted by the statistic software Statgraphics Centurion XVI on the significance level $\alpha = 0.05$.

Results of Research

The data processing followed the above defined research questions and hypotheses. First, reflecting the results of the Honey and Mumford´s Learning Styles Questionnaire (LSQ), four groups of respondents were formed according to the detected learning preferences. Absolute and relative frequencies in each group are displayed in Table 1.

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Table 1. Respondents' structure reflecting the learning style.

Learning style preference	Frequency (n)	Relative frequency (%)
Activists	61	18
Pragmatists	98	29
Theorists	105	31
Reflectors	68	20
Indifferent learning style	7	2
Total	**339**	**100**
Total research sample (learners with indifferent learning styles are not included):	332	100

The highest frequency was detected with theorists, the lowest one with activists; seven respondents were of the indifferent learning style – from this reason these learners were not included in the research sample. The high occurrence of theorists was surprising because this learning style is not typical for the age group of 15-year old learners, whereas the dominance of pragmatic learning style which more corresponds with the age specifics of pubescent cognitive development is more common (comp. Yuh-Shiow Li, Hsiu-Mei Chen, Bao-Huan Yang, Chin-Fang Liu, 2011). The high occurrence of theorists might be caused by a certain degree of learners´ adaptation on the scientific paradigm within the instruction of science subjects, which still survives in the Czech education system. This paradigm arises from the Zankov concept of developmental instruction, which prefers theoretical knowledge and high rate of abstraction. Particularly the learning contents of Physics and Chemistry are still influenced by this paradigm. The emphasis on abstraction and theoretical knowledge can cause the suppression of the pragmatic learning style which is more natural for this age in favour of required theoretic one.

Further data processing followed the hypotheses. Before the IBSE approach was applied to the teaching of 332 learners, they administered the didactic test (pre-test) (results of the seven pupils of indifferent learning style were not included) detecting the starting level of their knowledge in the field of science learning contents which were the object of the experimental teaching. In this way the impact of learner´s pre-concepts originating from previous formal and/or non-formal education on the total result of the experimental inquiry based instruction is excluded. The ANOVA test was applied on the pre-test results of the four groups of learning styles. The value of test criterion F (F-Ratio) = 2.28; the value of the significance level p (p-value) = 0.0793. The detected difference was not statistically significant. This result means that the impact of the observed parameter (individual learning style) was not proved in the pre-test. The null hypothesis H_{01} *was verified* saying that the level of learners´ pre-concepts before the inquiry-based science education started was not influenced by individual learning styles. Figure 1 displays the mean (see the crosses) and 95 percent Tukey HSD Intervals (see the line segments) of the pre-test in relation to learning styles.

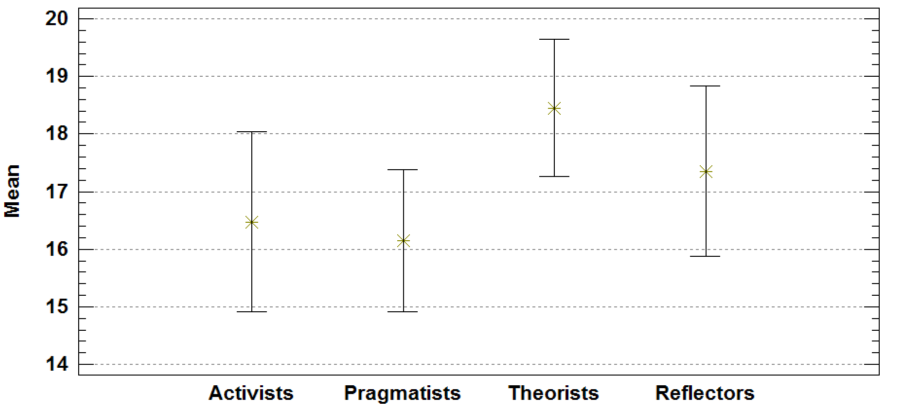

Figure 1: Means and 95 Percent Tukey HSD Intervals (Pre-test).

The figure clearly displays that the largest difference in the pre-test was detected between the pragmatists and theorists. However, this difference is not statistically significant, and all results are rather similar and close to each other. Reflecting the fact the total test score is 55, the pre-test score describing the starting level of learners´ knowledge before the experiment is rather high. The pre-test was applied in December 2013.

Then, from January to May 2014 the experimental inquiry-based science education was conducted in all science subjects (Physics, Chemistry, Biology). In June 2014 the post-test1 was administered. Identically to the pre-test, the post-test1 results underwent the ANOVA test. The value of test criterion F (F-Ratio) = 5.59; the value of the significance level p (p-value) = 0.0009. The detected difference is statistically significant. Therefore, another statistic analysis was conducted exploiting the Tukey HSD test for identification of statistically significant difference in means of four groups of learning styles. The statistical significance was detected between activists and theorists (difference in means = 4.836), between pragmatists and theorists (difference in means = 3.637) and between reflectors and theorists (difference in means = 3,622). Results are displayed in Figure 2.

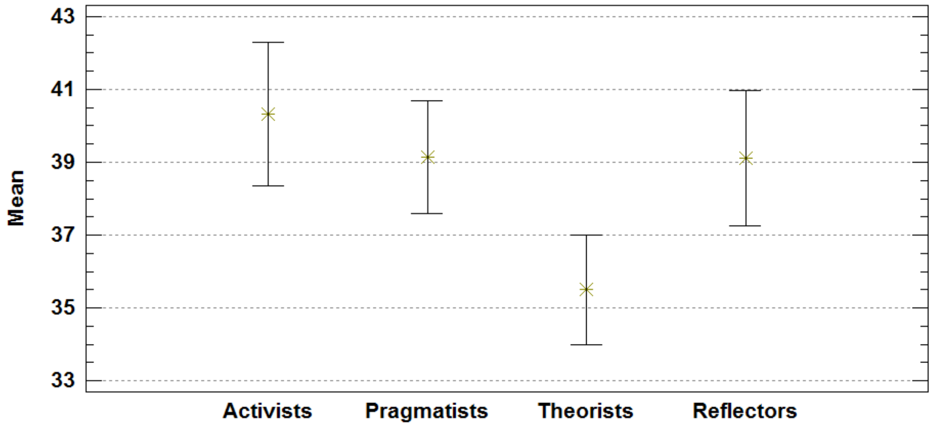

Figure 2: Means and 95 Percent Tukey HSD Intervals (Post-test1).

As the statistically significant differences were detected between single groups of learning styles, the null hypothesis H^0_2 *was falsified*. The lowest values were reached by theorists; results in other three groups were not statistically significant. Three learners reached the maximum test score (55 points), two of them been activists and one pragmatist. The highest test score in the group of theorists was 52 (one learner).

In October 2014, i.e. four months after the experimental inquiry-based science education and the post-test1, the post-test2 was administered as retention test to detect the level of long-time fixation of knowledge in science subjects. The post-test2 test scores underwent the ANOVA test. The value of test criterion F (F-Ratio) = 7.58; the value of the significance level p (p-value) = 0.0001. The detected difference is statistically significant. Therefore, as in the previous post-test1, further statistical analysis was applied exploiting the Tukey HSD test to identify statistically significant difference in means of four groups of learning styles. Statistically significant differences in means were detected in groups of activists and pragmatists (3.938), activists and theorists (4.714) and theorists and reflectors (3.095). Results are displayed in Figure 3.

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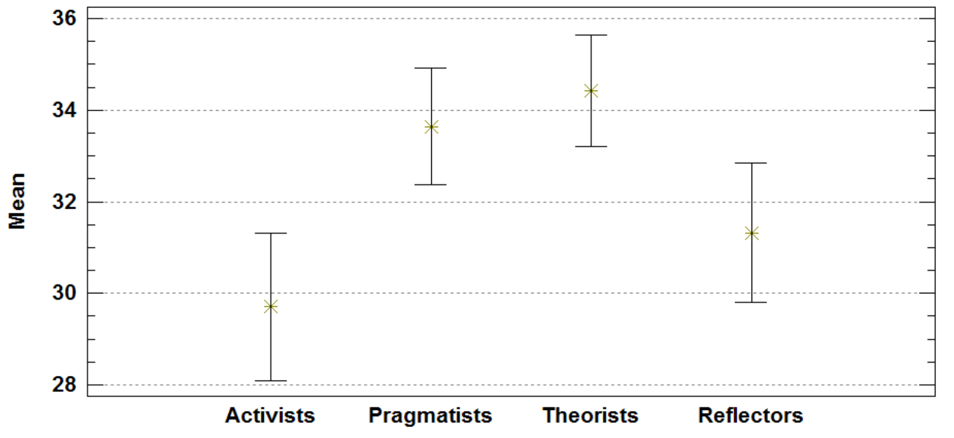

Figure 3: Means and 95 Percent Tukey HSD Intervals (Post-test2).

As the statistically significant differences were detected between single learning styles, this criterion provides impact on the results of post-test2. Therefore, the null hypothesis H^0_3 *was falsified*. The highest test score was reached by theorists, the lowest score by activists.

The mean values collected in single phases of the didactic test (pre-test, post-test1, post-test2) may not reflect the state to adequate extent because they operate with various input (pre-test – post-test1) and output (post-test1 – post-test2) levels of single learning styles. The comparison of *differences in differences* between single test scores in relation to pupils´ learning styles provided more valuable results. First, the differences in pre-test – post-test1 were compared, i.e. how the test score changed (increased) from the pre-test to post-test1. This difference can be interpreted as a direct result of the IBSE approach. Differences in pre-test – post-test1 in single learning styles were subjected to the ANOVA test with following results: F (F-Ratio) = 7.28; p p-value) = 0.0001. The detected difference is statistically significant. Therefore, another analysis was applied exploiting the Tukey HSD test for identification of statistically significant differences in pre-test – post-test1 differences in single learning styles. Results are displayed in Figure 4.

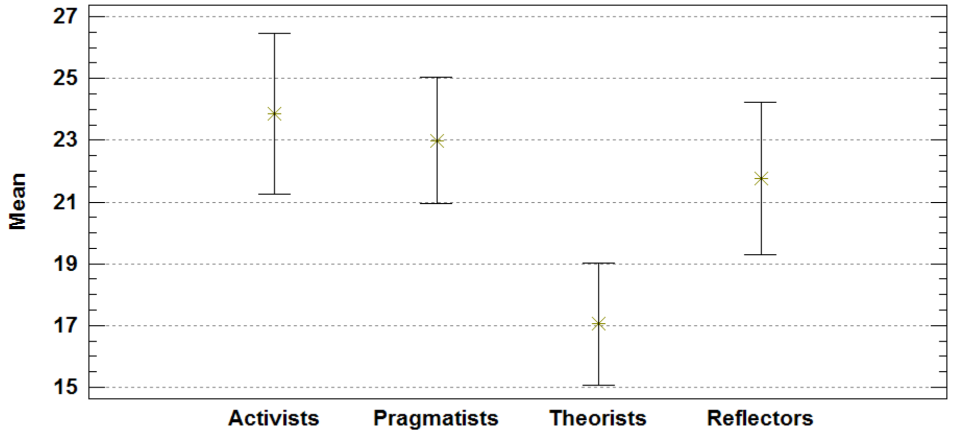

Figure 4: 7 Means and 95 Percent Tukey HSD Intervals (difference in pre-test – post-test1).

The highest mean increase in pre-test – post-test1 scores was detected with activists, the lowest difference with theorists. Statistically significant were the results between activists and theorists (difference in means = 6.804), pragmatists and theorists (difference in means = 5.942) and reflectors and theorists (difference in means = 4.717). Therefore, the null hypothesis H^0_4 *was falsified*.

The identical procedure was applied on considering differences in post-test1 – post-test2. The time period between the post-test1 and post-test2 was four months; this was multiplied by the fact that two months of four were holiday months (July, August), when no school lessons were conducted. The post-test1 – post-test2 difference follows the forgetting curve by Ebbinghaus (Custers, 2010). Although the IBSE is expected to strengthen the development of learners´ autodidactic strategies, the process of forgetting and the decrease in test scores is expected mainly in convergent questions focused on facts. Differences in post-test1 – post-test2 scores in single learning styles were subjected to the ANOVA test with following results: F (F-Ratio) = 11.32; p (p-value) = 0. The detected difference is statistically significant. Therefore, another analysis was applied exploiting the Tukey HSD test for identification of statistically significant differences in post-test1 – post-test2 in single learning styles. Results are displayed in Figure 5.

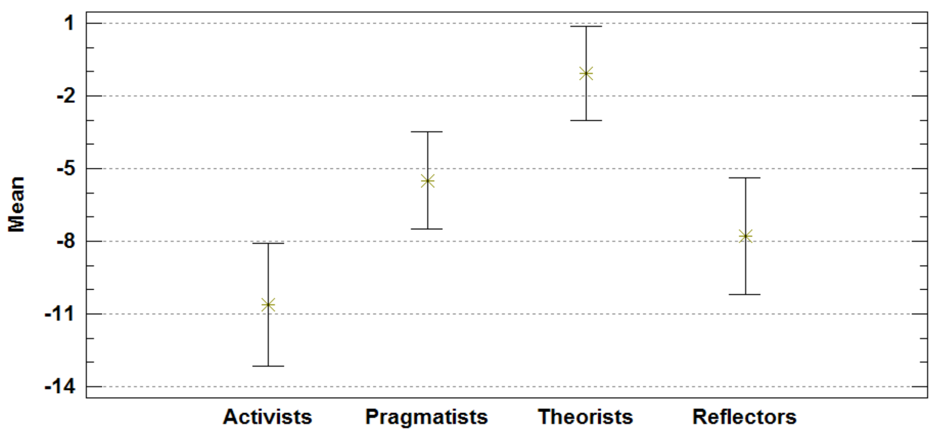

Figure 5: Means and 95 Percent Tukey HSD Intervals (difference in post-test1 – post-test2).

The highest decrease in the test scores was detected in the group of activists, the lowest one with theorists. Statistically significant were the results between activists and pragmatists (mean difference in differences = 5.133), activists and theorists (mean difference in differences = 9.547), pragmatists and theorists (mean difference in differences = 4.413), theorists and reflectors (mean difference in differences = 6.718). Therefore, the null hypothesis H^0_5 *was falsified.*

From the view of forgetting curve, the effectiveness of inquiry-based science education should be measured within the long-time period. The increase in test scores collected immediately after the instruction is rather considerable; however, it does not provide important evidence. The real effectiveness of any learning strategy (including IBSE) is supposed to be given by the developed competences which the learner disposes in a long-time scope. Therefore, the result between pre-test – post-test2 is considered more valid for the effectiveness of the inquiry-based science education. Differences in pre-test – post-test2 in single learning styles were subjected to the ANOVA test with following results: F (F-Ratio) = 3.63; p (p-value) = 0.0133. The detected difference is statistically significant. Therefore, another analysis was applied using the Tukey HSD test for identification of statistically significant differences in pre-test – post-test2 differences in single learning styles. Results are displayed in figure 6.

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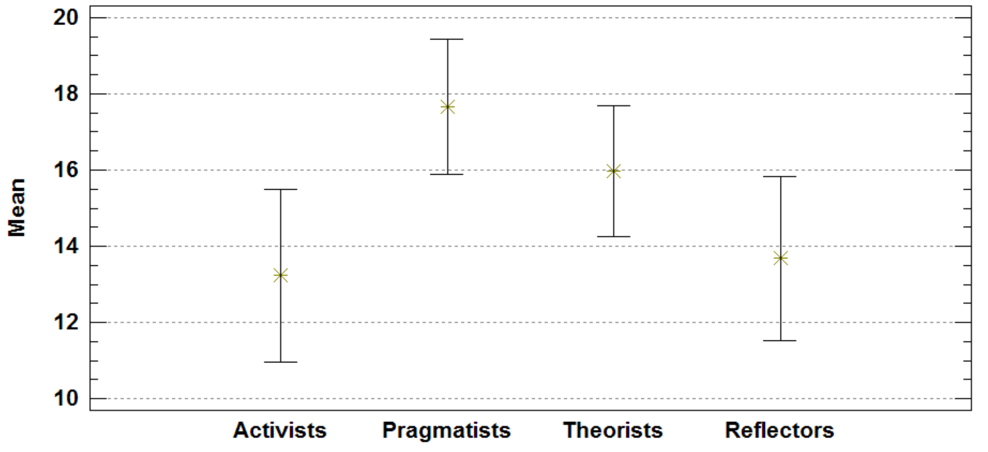

Figure 6: Means and 95 Percent Tukey HSD Intervals (difference in pre-test – post-test2).

The highest level of effectiveness of the inquiry-based science education in the long-time period was detected with pragmatists, the lowest one with activists. Despite the differences were not large, they were statistically significant between activists and pragmatists (mean difference in differences = 4.434) and pragmatists and reflectors (mean difference in differences = 3.987). Therefore, the null hypothesis H^0_6 *was falsified*.

Discussion

The inquiry-based science education brings substantial changes to the relatively-stereotyped traditional transmissive-instructive model of directing learning activities. This is confirmed e.g. by Lamanauskas (2013) who states that in the context of the fast increase of scientific cognition the commonly exploited educational strategies, teaching methods and organizational forms of instruction are re-considered. All the changes closely relate to directing the curriculum and make substantial impact on concrete educational strategies applied by the teacher in lessons. Then, changes in directing learning activities are directly connected with learning styles. The educational reality in the former Soviet bloc countries is (particularly in the science education) burdened by still remaining elements of scientific paradigm (Trna, Trnová, 2015). As mentioned above, this paradigm emphasizes theoretical knowledge, high degree of abstraction and mathematization. It is clearly visible in processes collecting the feedback on learning results (giving preference to knowledge of facts to their application, convergent thinking and designing creative and original solutions). Learners partially adopt to this educational reality through emphasizing elements of theoretical learning style despite it is not natural for the age group which participated in this research (compare to Coffield et al, 2004), and as it was proved by the results (see theorists in pre-test, figure 1). The inquiry-based science approaches to education arise from the constructivist models of directing the learning activities with the emphasis on the autonomous and active learners´ approaches and co-operative learning. These activities are mostly based on concrete sensing, observing the phenomena, experimenting etc. and suit mainly to activists and pragmatists. Some authors even state these approaches to learning are in accord with the cognitive architecture of human brain in the given age (Schmidt et al, 2007). This finding was also proved in our research, when activists and pragmatists reached the highest scores in post-test1. However, these results may not completely reflect the relevant effectiveness of IBSE; differences in pre-test and post-test1 with single learning style groups are of more significant value – the highest increase was detected with activists and the lowest one with theorists. The reasons are obvious – in the inquiry-based science education concrete facts, concrete objects, concrete processes and concrete phenomena are used. They are observed, the discussions on the observed are conducted resulting in generalization; in final phase of the inquiry-based science education general terminology and theories are deduced. Such a procedure is appropriate to concrete sensing and active and reflective processing of information, which is typical for activists and pragmatists. On the other side, it does not suit the theorists, who prefer abstract sensing and deductive thinking. Moreover, the emphasis on team and co-operative teaching does not suit the theorists because they do not like to work with persons of different learning styles (Kolb, Kolb, 2005).

And, hopeful results of activists are surprised by the highest rate of forgetting which, however, can be caused by insufficient process of knowledge fixation within the inquiry-based science education. Within descriptions of the IBSE strong attention is paid to the phase of forming knowledge but in practice hardly any attention is devoted to the fixation, when new information is integrated into existing mind and mental structures of the learner. The phase of fixation in IBSE is identical with the non-IBSE approach, been conducted in the form of revision. Therefore, more attention should be paid to creative and problem-solving approaches within the process of fixation. The hypothesis on insufficient fixation of new knowledge is also supported by the fact that the highest rate of forgetting was detected with activists and reflectors, i.e. those who process the information in the reflective manner. Therefore, further development of meta-cognitive strategies with learners of these learning styles should be emphasized, which could help them better exploit own mind processes for forming and fixing new knowledge. Another reason which could explain the difference between the test scores of post-test1 and post-test2 with activists is the fact that in this research the inquiry-based science education was the experimental activity only, and the return to the traditional transmissive instruction, which is least appropriate for activists, could be reflected in the fact they forgot more than learners of other learning styles. Compared to this, a low forgetting rate with theorists was surprising because the inquiry-based science education is not an optimal teaching strategy for them, which was expressed by the lowest increase in knowledge between pre-test and post-test1. However, as this is an active process, theorists process information better, similarly to pragmatists who also reached a low forgetting rate. The active processing of information thus contributes to the knowledge fixation. A reason could be a higher degree of meta-cognition the theorists and pragmatists exploit for information processing. For that matter, the selection of appropriate meta-cognitive strategies forms the basis of auto-didactic processes. Vermunt (1996) states mental models of learning and learning orientations turn out to be related to the way in which learners interpret, appraise and use instructional measures to regulate their learning activities. Therefore, as also resulted from this research, learners of concrete (not abstract) sensing acquire more short-time knowledge within the inquiry-based science education, which corresponds to activists and pragmatists. From the long-time period, the acquired knowledge is less forgotten by those who process the information actively, not reflexively – this is typical for theorists and pragmatists. The combination of both aspects results in the conclusion that in the long-time period the inquiry-based science education is the most effective with pragmatists because of their concrete sensing and active information processing. This hypothesis was verified by the research results, when the highest increase in test scores was detected between pre-test and post-test2 with pragmatists.

However, some limits should be considered which result from the experimental application of inquiry-based science education: (1) the validity of IBSE effectiveness should be evaluated within a long-time period of several years as minimum, similarly to the traditional transmissive instruction; (2) the IBSE should be exploited systematically and not in Science subjects only – the IBSE principles can be applied in the problem instruction in both Mathematics and Humanities (Škoda, Doulík, Bílek, Šimonová, 2015); (3) individual learning styles are not clear and unambiguous, but individual learning patterns consisting of a mixture of several learning styles can be detected with large amount of learners – each individual tends to a certain learning style; however, s/he is able to apply various learning strategies appropriate to the learning content, learning environment, age etc. and (4) the sample in this research was relatively small and geographically limited.

Conclusions

In this research attention was paid to learning styles which belong to the most important individual characteristics of learners. The learning style includes prevailing mind and metacognitive processes exploited by each learner, and their direct confrontation appears within the IBSE.

Generally, in above cited research studies both the immediate and long-time results on the IBSE effectiveness have been discovered. However, they should be clearly distinguished because they both are strongly influenced by learning styles. Immediate effects of IBSE are significant with concrete sensing learners who belong to activists and pragmatists. The IBSE, which is close to active constructing of knowledge, corresponds to the models of natural learning which is widely exploited by the 15-year old learners (pubescence/adolescence), as in the above described research sample. On the other hand, results of the long-time effectiveness of IBSE are higher with learners who actively process information, i.e. theorists and pragmatists. The higher long-time effectiveness of learning with theorists and pragmatists can be caused by higher level of meta-cognition and by acquiring of selected meta-cognitive strategies the learners apply to information utilization.

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Reflecting the variability of learning styles (numerous other classifications were defined besides the Kolb´s one), the IBSE cannot be considered a dogmatic methodological strategy following the pre-defined plan of activities and mind operations, as it often is in the real process of education. The IBSE should be flexibly modified so as learners´ competences towards scientific cognition of the world were developed, e.g. raising questions, collecting data, reasoning and reviewing evidence in the light of what is already known, drawing conclusions and discussing results.

Moreover, the findings also result in the recommendation that the directing of learning activities should not be "tailored" to single learning style preferences in the phases of presentation of the learning content. Teacher should facilitate the development of the optimal working procedure with learners of different learning styles which will also include the inquiry-based approach to problem solving. The IBSE should be conducted identically to the real scientific work, where various (both the correct and incorrect) ways are applied to problem solving. In IBSE, the learning objective is not the learners acquired a certain way of problem solving but they were able to discover the way/s by themselves reflecting their individual characteristics and specifics of the solved problem.

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