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ASSESSING OF SCIENTIFIC INQUIRY SKILLS ACHIEVED BY FUTURE BIOLOGY TEACHERS

OCENA UMIEJĘTNOŚCI NAUKOWYCH OSIĄGNIĘTYCH PRZEZ PRZYSZŁYCH NAUCZYCIELI BIOLOGII

Abstract: A successful application of scientific research in science education requires adequate professional training of teachers. The study presents the results of research focused on the level of scientific inquiry skills of future biology teachers. The results showed that students with a success rate of over 80 % solved tasks focused on applying numerical methods, determining relationships between variables and evaluating the uses and misuses of scientific information with a more than 80 % success rate. On the other side, the students had considerable problems associated with planning and implementing of the experiment. The results indicated that there is no significant difference in the level of scientific inquiry skills between students who study biology teaching in combination with other science subject, and students who study biology teaching in combination with a non-science subject.

Keywords: scientific inquiry skills, scientific knowledge

Introduction

The recent enormous growth of knowledge in many branches of natural sciences, including biology, and the development of both social and technical sciences have generated pressure on the system of education and strong demand for it being able to prepare individuals for a fully realised life and work in the global information society. A need has emerged along with these requirements to reconsider the undervalued significance of the teaching of natural sciences, as well as the context in which it is taking place. Available literature on science/scientific literacy in the context of science education mentions requirements for a wider application of scientific inquiry in teaching (see, for example [1-3]). Scientific inquiry is a systemic approach covering, in addition to more general scientific methods and procedures, processes involving the development of scientific knowledge, such as asking questions, creative problem solving, study of various sources of information, critical thinking, scientific reasoning and sharing and defence of conclusions [4-6]. Schwartz et al. [7] defined scientific inquiry as "(…) *the characteristics*

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of the processes through which scientific knowledge is developed, including the conventions of development, acceptance, and utility of scientific knowledge” (p. 3).

Scientific inquiry takes not only understanding science content but also acquiring and developing of general science process skills, creativity, and critical thinking to develop scientific knowledge [8]. Various terms appear in literature referring to the different skills students need to have to be able to engage in scientific inquiry, such as science process skills, science inquiry skills, inquiry skills, scientific inquiry skills or scientific literacy skills. Padilla [9] defines science process skills as “(…) *a set of broadly transferable abilities, appropriate to many science disciplines and reflective of the behaviour of scientists*” (p. 1). Depending on the level of pupils’ intellectual development, these skills are grouped into two types, basic and integrated.

Using science process skills, pupils not only gather new knowledge but also develop their understanding of scientific processes and methods which allow them to explore the surrounding world. Students need these skills as they use scientific reasoning and critical thinking to develop their understanding of science [10]. The development of science process skills has a great influence on developing mental processes such as critical thinking and decision making [11, 12]. According to National Research Council [4] inquiry skills include the abilities to conduct and understand scientific inquiry, including “(…) *asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analysing alternative explanations, and communicating scientific arguments*” (p. 105). Gormally et al. [13] define scientific inquiry skills as skills related to two major aspects of scientific literacy: a) recognising and analysing the use of methods of inquiry that lead to scientific knowledge, and b) organising, analysing, and interpreting quantitative data and scientific information.

A number of instruments have been designed to help to measure scientific inquiry skills. Gormally et al. [13] point out that while a number of instruments have been developed to assess the individual aspects of scientific literacy skills, there is no single instrument to measure all skills. The *Test of Scientific Literacy Skills* (TOSLS) designed by them measures the above-mentioned major aspects of university students’ scientific literacy using nine skill definitions. Wenning [14, 15] developed two standardised tests, the *Nature of Science Literacy Test* (NOSLiT) and the *Scientific Inquiry Literacy Test* (ScInqLiT), designed to assess the progress of students’ scientific literacy and teaching improvements and measure the efficiency of a programme in terms of the development of scientific inquiry skills. Dillashaw and Okay [16] designed the *Test of Integrated Process Skills* (TIPS) to measure integrated scientific process skills in pupils in the seventh to twelfth grades. Another set of test items able to serve as an alternative or equivalent test is proposed by Burns et al. [17] and it is referred to as TIPS II. Tobin and Capie [18] developed the *Test of Integrated Process Skills* (TISP), which is designed for secondary and university level students. Shahali et al. [12] focused on the understanding of science process skills by primary science teachers. They constructed the *Science Process Skills Questionnaire* (SPSQ) aimed at conceptual and operational understanding of science process skills.

Ledermann et al. [19] emphasize that "doing" of inquiry doesn't need to lead to the development of the understanding of scientific inquiry. Therefore, based on the instrument *Views of Scientific Inquiry* (VOSI) [7] constructed the instrument *Views About Scientific Inquiry Questionnaire* (VASI) for assessing learners’ conceptions about essential aspects of scientific investigations [19]. Both instruments [7, 19] focus on the understanding of scientific inquiry, not just students' actions while engaged in inquiry activities.

With a view to propose the systemic assessment of all aspects of a scientific inquiry Kruit et al. [20] focused on the construction of various instruments for measuring the science skills in grades 5 and 6 of primary education. They created an assessment that uses seven measures: a paper-and-pencil test, three performance assessments, two metacognitive self-report tests, and a test used as an indication of general cognitive ability.

Research objective and research sample

The transition from traditional to scientific inquiry oriented approaches to laboratory activities requires teachers to be ready to integrate such activities in their teaching processes and have active experience with some examples of scientific inquiry [21]. It is, therefore, inevitable at the pre-graduate study to pay increased attention to not only considerations about how scientific inquiry can be integrated into the teaching of sciences, but also the development of students' inquiry skills to help them to confidently apply their knowledge and skills in planning and conducting their lessons. This teachers' self-efficacy, which is created already at the education and training stage, is relatively firm and influences the approaches and methods the teacher employs in his or her teaching [22]. Our research was thus aimed at identifying the level of inquiry skills in students of biology teaching. Sufficiently developed scientific inquiry skills in teachers are the fundamental and inevitable prerequisite for quality and sophisticated incorporation of scientific inquiry in their own lessons.

The focus of our research represented the following questions:

- What level of inquiry skills do students of biology teaching have?
- Are there any differences in the level of biology teaching students' inquiry skills that are attributable to the second major subject?

The research sample comprised 45 students, future teachers of Biology (38 women and 7 men) who have ended their first year in the master's programme at the Faculty of Natural Sciences of Comenius University in Bratislava (Slovakia). The students were aged 23. Students in both bachelor's and master's programmes in teaching biology may choose to major in a combination of two educational subjects. Our sample included students studying Biology in combination with one of the following subjects: Chemistry, Geography, Mathematics, English language, Slovak language, Physical training, Psychology, Pedagogy, Civics, Environmental science, and Music. For the purposes of our research, we grouped those subjects into two categories: natural sciences (Chemistry, Geography, Mathematics and Environmental science) and humanities (English language, Slovak language, Physical training, Psychology, Pedagogy, Civics and Music). The number of students in the Biology/sciences group was 26 and the number of students in the Biology/humanities group was 19. The survey was undertaken in May 2018.

Methods

We used a closed question test to examine the students' inquiry skills. The test is primarily intended for the examination of inquiry skills in students of secondary grammar school. We designed our research instrument on the basis of the papers by Fradd et al. [23], Wenning [15] and Gormally et al. [13]. We targeted our research at two areas of inquiry skills:

a) Methods and procedures of science, including the skills needed in the different inquiry phases; and
b) Integration of science into life, including the recognition of scientific knowledge and its utilisation in making informed decisions based on a critical review and assessment of arguments supported by evidence.

Then, we identified the inquiry skills to be examined for each category (Table 1). The selection of skills was limited by the scope of the test and the resolution to employ solely closed-ended items. After that, we discussed each skill sample with experts in the relevant area.

Table 1

Inquiry skills identified in the areas of focus

Area	Skills
Methods and procedures of science	Formulate a hypothesis
	Plan the experiment
	Collect meaningful data from observation and measurement
	Transform the results into standard forms
	Formulate conclusions
	Identify relations between variables (using a graph)
	The application of numerical methods of data analysis
	Identify the accuracy of experimental data
Integration of science into life	Evaluate the credibility of literature
	Understand elements of research design and determine their effects on the research conclusion
	Evaluate correct and incorrect uses of information (correct uses of science for social purposes)

To measure each skill, we constructed two closed-ended items with one correct answer. All formulated items covered situations based solely on examples of the implementation of scientific inquiry approaches in biology. We designed the test with the use of those items and presented the test to three competent experts to ensure the validity of our research instrument. In order to check the comprehensibility of our formulations of the test items and distractors and to determine the testing time, we made a pilot trial with a small sample of secondary grammar school students. We interviewed the students to identify any problems they may have encountered in solving the test items. Based on the trial, we made necessary modifications of the measurement instrument and then performed another trial with a larger sample of respondents. The final test contained 22 items, each having one correct answer and four distractors. Each skill was measured by two items. The "methods and procedures of science" category contained sixteen items and the "integration of science into life" category six items. The administration of the test took 45 minutes and the students were not allowed to use any aids and information sources during the test. One point was awarded for a correct answer and no point for an incorrect answer (i.e. choice of one of the distractors). The maximum obtainable test score was 22 points.

We measured the reliability of the test using the Kuder-Richardson Formula 20 (KR20). The reliability of our test achieved the value 0.65. Based on Hair et al. [24] and Christmann and Van Aelst [25], we can consider our research instrument to be reliable.

To confirm the normal distribution of our data, we performed the Shapiro-Wilk test and the normality of distribution of data was not denied ($W = 0.96$; $p = 0.22$). In further statistical analysis, we compared the two samples using the Student *t*-test for two independent samples. The *t*-test was chosen on the basis of an *F*-test comparison of standard deviations. The comparison of answers to questions for each skill was performed using a chi-squared test.

Results

Level of students' inquiry skills

The minimum and maximum scores in the test were 8 and 21, respectively. The median value was 16. The average score, *X* was 15.42 and standard deviation, *SD* was 3.14.

The students achieved their best problem solving results (I = 99 %) in items involving calculations (Skill 7, Table 2). Those items required the use of mathematical skills and understanding of the necessity of statistical data processing to quantify the risk of error and evaluate the accuracy and reliability of research outcomes.

Table 2

Rate of success in solving the test items grouped by inquiry skill

Area	Skill		Item	Success rate for item [%]	Success rate for skill [%]	Success rate for category [%]
Methods and procedures of science	1	Formulate a hypothesis	3	87	73	68
			16	60		
	2	Plan the experiment	4	47	48	
			12	49		
	3	Collect meaningful data from observation and measurement	6	93	70	
			17	47		
	4	Transform the results into standard forms	2	62	58	
			18	53		
	5	Formulate conclusions	9	49	64	
			19	80		
	6	Identify relations between variables	7	78	81	
			20	84		
	7	The application of numerical methods of data analysis	8	100	99	
			14	98		
	8	Identify the accuracy of experimental data	10	36	48	
			21	60		
Integration of science into life	9	Evaluate the credibility of literature	1	96	76	77
			13	56		
	10	Understand elements of research design and determine their effects on the research conclusion	5	84	71	
			15	58		
	11	Evaluate the correct and incorrect use of information	11	78	83	
			22	89		

We also obtained relatively satisfactory results with regard to the items measuring further two students' skills. A success rate average of 83 % was achieved in items concerning the evaluation of correct and incorrect uses of scientific information (Skill 11). The students were expected to recognise, from a scientific perspective, valid approaches to publishing outcomes of scientific research and to evaluate a presented situation in which results of science and scientific procedures were used to advocate government resolutions.

The second tested skill with regard to which the students achieved the success rate of 81 % was the ability to identify relations between variables from graphical representations of information (Skill 6). Correct problem solution required the students to appropriately read and interpret data expressed by graphs.

A success rate below 50 % was achieved by the students with regard to skills concerned with planning experiments and assessing the accuracy of experimental data (Table 2). The test revealed that the students had a major problem determining a dependent variable in a given, exactly described experiments. While the students correctly identified the variable, they were not able to distinguish between dependent and independent variables. The lowest success rate (I = 36 %) was observed in the item 10 where the students were expected to establish the factors in a described experiment which influenced the experiment outcome. In most cases, the students chose the option that none of the proposed answers was correct.

We observed a large difference in the problem solving success rates for certain skills. Based on the results of a chi-squared statistical test, the differences were statistically significant for those items which measured the skills 1, 3, 5, 8, 9 a 10 (Table 3). A comparison of solutions for the skill 1 revealed that students achieved a statistically significantly better problem solution results for the item 3 in which they were asked to choose a correct hypothesis whose testing would provide a valid answer to the given question ($\chi^2 = 8.18$; $p = 0.004$). The students were expected to apply their knowledge of hypothesis formulation rules, e.g. that a hypothesis should be a statement which contains two variables and the variables should be exactly measurable, etc. As many as 39 students (I = 87 %) chose the correct answer. Major problem solution difficulties were observed with regard to the second item (Item 16) where the students were required to choose the incorrect hypothesis out of the offered options about a described problem. All hypotheses were formulated correctly but contained different variables. This problem was solved correctly by only 27 students (I = 60 %). The result supported our findings regarding the skill 2 that students had difficulties in defining and distinguishing dependent and independent variables.

The largest difference was observed in the items measuring the ability to record results in standard forms (Skill 3). The students were asked in those items to choose an appropriate table or graph to record or represent the results of a particular experiment. The students achieved the success rate of 93 % in the item 6 where they were expected to identify the graph with the correct x and y axis descriptions. However, their success rate in the problem requiring them to identify the correct table (Item 17) was only 47 %. Similar results were observed for the skill 5. The students achieved statistically significantly better results ($\chi^2 = 9.50$; $p = 0.002$) in an item where they were expected to formulate a conclusion based on a graphical representation of results (Item 19) than an item with results presented in a table (Item 9). This outcome indicates that students have a problem constructing and interpreting tables, despite this being an efficient method of visualising relations between data. A tabular representation of data is the most frequent approach to presenting basic (source) statistical data which is widely used as an input for further analysis and decision-making.

A statistically significant difference in problem solution results was also found in items concerning the skill 8 which involved the determination of the accuracy of experimental data ($\chi^2 = 5.39$; $p = 0.020$). Students had difficulties identifying the factor able to affect the outcome of the experiment. The most frequent incorrect answer selected by students in item

10 (I = 36 %) was that none of the options was a potential source of measurement error. This suggests that the students disregarded the fact that a clear indication of the measurement length was lacking in the experiment description. Interestingly, a similar measurement error (an unambiguous indication of the numbers of seeds in different containers) in another item was identified by as many as 27 students (I = 60 %).

A statistically significant difference in problem solution results was also found in items concerning the skill 9 which regards the evaluation of the credibility of literature ($\chi^2 = 19.49$; $p = 0$). The item 1 was solved correctly by all but two respondents. The item was concerned with the evaluation of the credibility of information published on a particular website. The students correctly determined that the information was not credible because it did not contain results of concrete studies published in peer-reviewed journals. The students had major difficulties in solving the item 13 which required them to generally identify the factor to be used as the basis for credibility evaluation of studies published in a journal or in other media. In this case, only 25 students (I = 56 %) correctly answered that the factor was an independent peer review. The most frequent incorrect answer was the presence of references to other sources of literature. The foregoing clearly indicates that a relatively large number of students do not realise the significance of, and need for, an objective peer review of research results. It is the collective nature of science that determines what should and what should not be included in the body of scientific knowledge.

Table 3

Chi-Square values for the different skill measures

Skill number	**Task number**	**Count of correct answers**	**Count of incorrect answers**	**Chi-Square**	***p*-value**
1*	3 16	39 27	6 18	8.18	0.004
2	4 12	21 22	24 23	0.05	0.833
3*	6 17	42 21	3 24	23.33	0
4	2 18	28 24	17 21	0.73	0.393
5*	9 19	22 36	23 9	9.50	0.002
6	7 20	35 38	10 7	0.65	0.419
7	8 14	45 44	0 1	-	-
8*	10 21	16 27	29 18	5.39	0.020
9*	1 13	43 25	2. 20	19.49	0
10*	5 15	38 26	7 19	7.79	0.005
11	11 22	35 40	10 5	2.00	0.157

* $p < 0.05 \rightarrow$ significant difference

The last skill where we identified a statistically significant difference in problem solving was the skill 10 where the students were required to evaluate various elements of research design and determine their effects on the conclusion (χ^2 = 7.79; p = 0.005). The students achieved the success rate of 84 % in an item where they were expected to evaluate the sample size and its impact on the reliability of results (Item 5). On the other hand, only about a half of the students were able to correctly assess what age structure a research sample should have to ensure that it is representative of the whole population to which the generalised conclusions and outcomes of the research would be applied (Item 15).

In terms of the different categories, the students achieved better results in solving problems concerned with the integration of science and its results into the different areas of social life and personal life. Those skills were closely interlinked with the individual's ability to make informed personal decisions about matters involving science (such as health, nutrition, etc.) and to read, understand and critically evaluate scientific information published in the media. From our perspective, a low level of success was achieved in the "methods and procedures of science" category, which covered the skills required for ~~a~~ targeted conduct and direction of the pupils' scientific inquiry in class.

Level of students' inquiry skills driven by the second major subject

The aim of the second part of our analysis of test results was to establish whether students in a programme combining Biology with a second natural-science teaching subject had better inquiry skills than students with a non-scientific second teaching subject. The test results showed that there was no difference in the level of inquiry skills between the two student groups (t = –1.13, p = 0.266). The average test success rate for students with a combination of two science subjects, i.e. Biology and Chemistry/Geography/ Mathematics/Environmental science was 72 %. Their average score was 15.85 (SD = 3.28). For students with a combination of Biology and non-science subject (humanities), the success rate was 67 %. The average score was 14.78 (SD = 2.90).

A comparison of the two groups' success rates in the different skill categories revealed no difference between them. Our assumption that students in a programme combining two science subjects have better inquiry skills in the "methods and procedures of science" category was not confirmed (Table 4).

Table 4

Comparison of *t*-test values by skill category between the student groups having a combination of Biology with a science subject and with a non-science subject

<table>
<tr><th rowspan="2">Subjects</th><th colspan="4">I. Scientific methods and techniques</th><th colspan="4">II. Integration of science into life</th></tr>
<tr><th>Mean</th><th>SD</th><th>t-test</th><th>p-value</th><th>Mean</th><th>SD</th><th>t-test</th><th>p-value</th></tr>
<tr><td>Biology and a science subject</td><td>11.26</td><td>2.68</td><td rowspan="2">–1.35</td><td rowspan="2">0.184</td><td>4.59</td><td>1.19</td><td rowspan="2">0.06</td><td rowspan="2">0.954</td></tr>
<tr><td>Biology and a non-science subject</td><td>10.17</td><td>2.62</td><td>4.61</td><td>0.85</td></tr>
</table>

Conclusions

Successful application of scientific inquiry in the teaching of science requires a sufficient level of teachers' professional readiness. Therefore, what needs to be developed in future teachers to make them being able to plan and carry out scientific inquiries is the understanding of not only scientific concepts~~,~~ but also of the formation of scientific knowledge. Only teachers having well-developed inquiry skills can drive transition from traditional laboratories that offer pupils 'cook-book' assignments to labs able to give pupils opportunities to ask questions, formulate hypotheses, design and realise experiments, critically evaluate the results of their work, discuss, argue and defend their statements on the basis of scientific evidence, etc. The purpose of pre-graduate study is to adequately prepare teachers from both the subject-matter (biological content) and pedagogical perspectives to ensure that new young teachers have the necessary self-confidence and reliance on their ability to integrate various teaching methods and approaches in their lessons in order to develop in their pupils both the conceptual and procedural understanding, positive attitudes to science and scientific work, proper value orientation, and willingness to engage as reflecting citizens in the addressing of topics linked to science.

Having analysed the test items/skills, our finding is that the best results were achieved in the items involving the application of numerical methods of data analysis and the ability to identify relations between variables. Our survey has revealed that the students as future biology teachers have notable problems planning and conducting an experiment. In many cases, the students were not able to distinguish between dependent and independent variables. We also observed difficulties in identifying the accuracy of experimental data: the students had problems identifying the various possible sources of error able to affect (distort) the results of an experiment.

There are many potential causes of the low level of students' inquiry skills. We believe that one of them is the absence of scientific inquiry as part of the pre-graduate education and training of future teachers. It is inevitable to systemically and consistently implement scientific inquiry activities both during biology courses in bachelor's programmes and in didactic training at the master's level of study.

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OCENA UMIEJĘTNOŚCI NAUKOWYCH OSIĄGNIĘTYCH PRZEZ PRZYSZŁYCH NAUCZYCIELI BIOLOGII

Abstrakt: Skuteczne zastosowanie badań naukowych w edukacji naukowej wymaga odpowiedniego przeszkolenia zawodowego nauczycieli. W opracowaniu przedstawiono wyniki badań dotyczących poziomu umiejętności badawczych przyszłych nauczycieli biologii. Wyniki pokazały, że 80 % studentów z powodzeniem rozwiązywało zadania polegające na stosowaniu metod numerycznych, określaniu relacji między zmiennymi oraz ocenianiu prawidłowego i nieprawidłowego wykorzystania informacji naukowej. Z drugiej strony studenci mieli znaczne problemy związane z planowaniem i realizacją eksperymentu. Wyniki pokazały, że nie ma znaczącej różnicy w poziomie umiejętności prowadzenia badań naukowych między studentami, którzy studiują nauczanie biologii w połączeniu z innym przedmiotem nauki, a studentami, którzy studiują nauczanie biologii w połączeniu z przedmiotem nienaukowym.

Słowa kluczowe: umiejętności prowadzenia badań naukowych, wiedza naukowa