FORMATIVE ASSESSMENT AND ITS IMPLEMENTATION INTO TEACHING SCIENCE, MATHEMATICS, AND INFORMATICS

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Abstract

The contribution informs about a new publication entitled "Formative Assessment and Its Implementation into Teaching Science, Mathematics, and Informatics" published by Wolters Kluwer in Slovakia in 2022. This publication is dedicated mainly to teachers working at all levels of education, teachers in training, pupils and students, and also their parents. It is available in common bookstores. The first part of the publication aims to explain the theory of formative assessment and its relationship to summative assessment. It deals with the strategies and tools of formative assessment focused on the development of conceptual understanding as well as meta-cognitive strategies. It provides the reader with an opportunity to learn how formative assessment is implemented in teaching and the types of digital platforms and tools that can make this process more efficient. The second part of the publication provides demonstrations of strategies and formative assessment tools (FACTs) for the selected Science subjects (Biology, Physics, Chemistry), Mathematics, and Informatics whose didactic efficiency has been verified in practice. The publication draws from respected scientific studies on formative assessment abroad and in Slovakia. The research team behind this publication has also gained valuable experience during formative assessment training courses, which they organised for primary and high school teachers. This team created and verified formative assessment tools in cooperation with teachers themselves and performed several research studies investigating the influence of formative assessment on the development of conceptual understanding and scientific skills.

Keywords: *formative assessment, strategies and tools of formative assessment, implementation, conceptual understanding, scientific skills*

1. INTRODUCTION

The methods of assessment in the Slovak Republic (SR) lag behind the general world trend, which focuses on distinguishing what the student knows and is capable of in the given period, and the process through which the student achieved the results. The feedback to the student is limited to the areas on which the pupil should work harder instead of the actual ways to improve. In the SR, it is not specified whether grades reflect the results, the process, or students' progress. As a result, teachers, students, and parents are not informed how well the student performed in terms of the subject-specific outcomes, whether the student made progress, or how the student's activity and responsibility for their own learning outcomes was assessed. A single grade per subject is supposed to express all of the above.

However, in the OECD Reviews of Evaluation and Assessment in Education: Slovak Republic 2014 (Shewbridge et al. 2014), the OECD education experts recommended that the Slovak educational system incorporate "formative assessment elements" to capture not only "what" the pupils are learning and "what results" they achieve, but also "how" they are learning.

Formative assessment (FA) based on regular interactive evaluation of students' work provides feedback on students' learning and their progress towards achieving the determined goals. It also helps identify what needs more attention and what steps need to be taken to achieve progress. Therefore, FA contributes to an overall learning improvement.

The publication entitled Formative Assessment and Its Implementation into Teaching Science, Mathematics, and Informatics (Ganajová et al. 2022) published by Wolters Kluwer in Slovakia in 2022 can be helpful in the implementation of FA. This paper presents selected knowledge from this publication. The first part explains formative assessment and its tools (also referred to as "formative assessment classroom techniques" or "FACTs") focused on the development of conceptual understanding as well as the metacognitive tools. This part is complemented with science (biology, physics, chemistry) and mathematics FACTs demonstrations emphasizing their didactic efficiency in teaching the selected topics verified via teaching. The second part presents information on how the teacher should proceed in the implementation of formative assessment. Useful digital platforms and tools increasing the efficiency of FA implementation are also discussed.

2. WHAT IS FORMATIVE ASSESSMENT

There is no single officially valid and generally accepted definition of formative assessment. The OECD (2005, p. 22) has defined formative assessment in the broadest sense by emphasizing student progress: it helps to "identify learning needs and adjust teaching accordingly". The more recent reviewed version defines formative assessment as a process, which is planned and continuous; students and teachers benefit from it in learning and teaching respectively. FA provides the teacher with information on their students' learning process including the progress in their understanding (CCSSO 2018). It also points out the importance of support provided by teachers, which helps students become independent individuals during the learning process.

The following key points can be drawn from the aforementioned characteristics:

1. Formative assessment takes place during classes.
2. It is not an examination or a test; it is a planned process integrating a number of diverse activities.
3. It is performed by both teachers and students.

FA provides an opportunity to identify the actual state of students' learning and allows for a response while it is still possible to provide feedback, which will help the student learn and improve (Cowie & Bell 1999). The goal of feedback is to obtain information on students' learning, i.e. reveal, and diagnose shortcomings, mistakes, difficulties and their reasons. Based on this kind of analysis, learning can be made more effective. Feedback also helps determine the difference between the actual level of students' performance and the required standards. Feedback is usually provided by the teacher, but peer feedback is also very important.

FA informs the student about the quality of their own learning and it is rarely used for grading purposes (Orna 2010). It takes the form of mutual feedback between the teacher and students (Harlen 2013). FA is used as appropriate, necessary, and feasible (daily, weekly, monthly). It can take an oral or written form before, during, or after classes (Tomengová 2012). It has been designed to promote students' self-regulation in learning (Orna 2010). Therefore, the major emphasis is put on active participation of students through the process of self-assessment, peer-assessment, and combining teacher and student assessment.

3. FORMATIVE ASSESSMENT TOOLS FOCUSED ON DEVELOPING CONCEPTUAL UNDERSTANDING

The FA focused on cognitive processes allows for identification of how well the student understands new concepts and contexts, and thus helps to develop cognitive processes. Cognitive processes integrate problem-solving strategies such as analysis, synthesis, induction, deduction, analogy, specification, generalisation, etc.

If the teacher plans to focus FA on cognitive processes and the development of conceptual understanding, they should choose appropriate FACTs corresponding with the goals set.

There are different types of FACTs, which can stimulate students' cognitive processes. The can be categorised into groups as follows: 1) asking questions, 2) prediction, 3) enhancing the understanding concepts and relationships, 4) inference and conclusion drawing, 5) rubrics, analysis, and assessment of students' performance (Ganajová et al. 2022).

In the following part, selected FACTs will be characterised and demonstrations using topics in mathematics and physics will be provided.

3.1. Prediction card

In terms of teaching strategies, prediction invites the student to activate and apply their existing knowledge and experience to formulate and subsequently verify their own predictions or hypotheses regarding the behaviour of a system (object, phenomenon, or process). Based on students' justifications (related to predictions or the discrepancy between predictions and findings), the teacher can identify students' preconcepts and misconceptions (Ganajová et al. 2022).

The creation of predictions and formulation of explanations can be performed using a prediction card, which takes the form of a table. Besides the assignment, the table also includes the fields into which the student is supposed to fill the answers.

3.1.1. Prediction card: demonstration in mathematics

Table 1 shows an example of the prediction card, which could be used in teaching the topic of Probability during mathematics at secondary schools (Lukáč 2020).

Student's name:	**Form:**		**Date:**	
Joe invited his two friends, Mike and Peter, to play dice. In this game, two dice are rolled and the points are counted. If Mike or Peter guesses the sum of points on the dice correctly, they win the round. If no one guesses the sum of points on the dice correctly, Joe wins the round. Mike's guess was 12 and Peter's guess was 11.				
Question	**Prediction**		**Answer**	
Are Mike's and Peter's chances to win this game the same?	yes	no	yes	no
Explanation:				

Table 1. The prediction card dealing with the probability of specific outcomes in a game involving two dice (secondary school, 2nd year)

Source: Lukáč 2020

After formulating their predictions, students can play a few rounds of the dice game. After recording and evaluating the results of several game rounds, students should be able to find out that Peter has a better chance to win than Mike. To explain this conclusion, a list of possibilities, which would allow for Mike and Peter to win respectively, can be written down. Since dice are two different physical objects, Peter's guess can be correct in two cases (if the dice show 6, 5 or 5, 6 points). This idea can be further developed and students can be asked which sum of points occurs most frequently when two dice are rolled.

3.2. Frayer model

The goal of the Frayer model (Frayer, Fredrick & Klausmeier 1969) is to identify and define concepts. Students analyse a concept, formulate its definition and basic characteristics, and subsequently, they synthesize this information, and apply it by coming up with specific examples and counter-examples. In teaching, this can be done in two ways (Ganajová et al. 2022). If the concept is new and unfamiliar to the students, the teacher can used this model to activate their preliminary knowledge about the concept. In this case, the model created by students allows for the identification of possible misconceptions or incorrect knowledge/experience, which could potentially interfere with students' understanding of the concept presented. Based on in-class activities, students can modify and improve their model. This model can also be used to enhance the understanding of a familiar concept. Students are asked to analyse the concept (formulate its definition and characteristics) and provide specific examples and counter-examples, which enhances their understanding by using a broader context. This allows the teacher to obtain information about their current level of understanding.

3.2.1. Frayer model: a demonstration in physics

The Frayer model can be used in teaching the topic of Work (before defining this concept) to identify students' ideas about it. Students may provide an example like this: "We are doing some work when we carry a bag of groceries". In ordinary life, such formulation is possible, however, it is not a correct definition of this concept in physics. It provides an opportunity to point out the difference between the way this word is used in common conversation versus when it refers to a concept in physics. The other way is to use the Frayer model after defining the concept of work to enhance or verify understanding (Tab. 2). It is desirable to complement this model with a picture showing the situation.

Student's name:	**Form:**	**Date:**
Definition Work is performed if a physical object is moving. $W=Fs$, where F is the magnitude of the force acting in the direction of motion, s is the distance travelled by the object.	**Characteristics/Properties** Work depends upon the magnitude of force F acting in the direction of motion and the distance travelled by the object. The unit of work is J=Nm.	
Work		
Examples When we are pulling a sled, our force is doing work. When we are pushing a car, this force is doing work. When we are lifting an object, our work is doing work. If an object is falling, the gravitation force is doing work.	**Counter-examples** If the force is perpendicular to the direction of motion, no work is being done. For example, the gravitation force by which the Sun is acting on the Earth is not doing work.	

Table 2. Frayer model for the concept of Work to enhance understanding – a demonstration of students' work (primary school, 8th grade)

Source: Ganajová et al. 2022

4. METACOGNITION AND METACOGNITIVE FORMATIVE ASSESSMENT TOOLS

The Dictionary of Pedagogy (Průcha, Walterová & Mareš 2008) defines metacognition as one's ability to plan, monitor, and evaluate the processes through which they learn. This conscious activity allows one to realize how they proceed when they are learning about the world. Everyone has the ability to perform metacognition and its strategies; it improves as the person ages. An important factor in this process is education, since the performance of tasks and subsequent feedback significantly affects the development of metacognition in children when their schooling begins (Mesárošová, Bavoľár & Slavkovská 2018). In terms of education, the term metacognition refers to the students' ability to analyse their own learning and control it efficiently (Flavell 1979).

The question is how metacognitive abilities can be developed via teaching. This paper presents some possibilities for using the selected FACTs for the purpose of metacognition development via specific topics in biology and chemistry.

4.1. Self-assessment card – characteristics of the tool

Self-assessment cards can take different forms based on the type of questions and answers to choose from. Questions can focus on self-assessment of the process or of the learning outcomes. Students' answers in the self-assessment cards provide the teacher with feedback based on which they can correct the previous teaching interventions and plan the next ones.

4.1.1. Prediction card: demonstration in chemistry

Topic: Investigation of acid solutions

The self-assessment card in Table 3 was filled in by 23 students in the 8th grade of primary school during laboratory work focused on the "Investigation of acid solutions" topic. It helps them perform self-checks and self-evaluation and provide evidence on their knowledge and skills in the context of this topic. The teacher focused on the desired goals in terms of knowledge and skills, which the students were supposed to learn and develop during three lessons (Household acids, Acid-base indicators/pH indicators, Properties of acids).

Student's name: **Form:**	**Date:**		
Level of understanding of the subject matter	**On my own** number	**With the teacher's assistance** number	**I don't understand it yet** number
I can name three examples of acids, which are used in a household and/or a laboratory.	18	3	2
I can write down chemical formulae of three different acids.	12	6	5
I can describe the first aid needed if someone spills an acid on themselves.	19	3	1
I can explain how acids are diluted with water.	18	3	2
I can name the cations, which cause the acids to be acidic.	15	5	3
I can write down the equation of hydrochloric acid ionization in water solution.	12	5	6
I can explain what indicators are.	16	5	2
I can provide some **examples** of indicators.	20	2	1
I canidentify the pH of a solution using a universal indicator paper.	17	4	2

Table 3. Evaluation of a self-assessment card after teaching the topic Investigation of acid solutions (primary school, 8th grade)

Source: Ganajová et al. 2022

Upon evaluation, the self-assessment cards indicate what knowledge the students can tackle on their own and in which cases they need some help (Tab. 3). Most students stated they knew examples of acids used in households and/or laboratories and they could also identify a solution pH using a universal indicator paper. Some students were unsure about acid formulae and the equation about hydrochloric acid ionization in the water solution. Therefore, during the next lesson, the teacher revised the names and symbols of chemical elements, classification of acids into oxyacids and non-oxyacids, and the rules for creating formulae and names of acids using specific examples and didactic games. The teacher stated that using self-assessment cards in the evaluation stage motivated students to focus and try harder during the following lessons.

4.1.2. Self-assessment card: demonstration in biology

Topic: Life of a forest

Student's name: **Form:** **Date:**			
Level of understanding of the subject matter	**On my own**	**With the teacher's assistance**	**I don't understand it yet**
I can provide two examples of animals that live in a forest.			
I can specify the forest layer in which mice live.			
I can explain how the seasons differ in a deciduous forest.			
I can describe a food chain consisting of at least three organisms.			

Table 4. Self-assessment card applied after teaching the "Life of a forest" topic (primary school, 5th grade)

Source: Own processing

In the reflection phase, students fill in the self-assessment card (Tab. 4), which allows for the identification for possible misconceptions in this area. Misconceptions can be eliminated by discussing which organisms live in forest environments or which organisms feed on mice, which allows students to describe a food chain correctly, or how a forest changes throughout the year, etc.

4.2. Exit card – characteristics of the tool

Wormeli's research (2004) has shown that students who summarise their knowledge achieve deeper understanding and remember the subject matter for a longer time. The exit card is used at the end of the lesson or upon completion of a topic. Fisher and Frey (2004) have claimed that this FACT allows students to summarise the key elements of the subject matter learned recently and identify the important details. Students answers the teacher's questions about the goal, course, or efficiency of the lesson(s). Besides informal diagnostics of the educational goals and their achievement, students' answers also provide feedback on the course of lessons based on which the teacher can plan further teaching interventions. Some students' answers can provide more objective information about the individual's learning process or their knowledge.

4.2.1. Exit card in chemistry: demonstration

Topic: Properties of plastics – burning plastics

This example of a filled-in Exit card shows the answers 22 students in the 2nd year of grammar school upon completion of the "Properties of plastics – burning plastics" topic. The topic was taught using an inquiry-based approach. In the "Burning plastics" activity, students performed an experiment to identify the flammability of the selected types of plastic and described the phenomena accompanying burning (flame colour, smell, smoke emission, nature of the fumes) using a universal indicator paper. It took the form of controlled inquiry.

Student's name:	**Form:**	**Date:**
Topic: **Properties of plastics**		
Today I learned…	About the properties of different plastics. About the types of plastics. How to ignite a burner. How different plastics burn. Which plastics smell and drip when they burn. What plastics are used for.	
The most interesting for me...	Was how plastics behave when they burn. Burning a table tennis ball. How many things are made of plastics. The colour of flame. The smell.	
I would still like to ask...	How can plastics harm us? How to prevent the generation of too much plastic waste? Why do plastics burn like this? Why don't we learn this way more often? I have no questions.	

Table 5. Selected student answers provided in the Exit cards upon completing the "Properties of plastics – burning plastics" topic (secondary school, 2nd year)

Source: Ganajová et al. 2022

Students' answers show what they learned about the types of plastics, their properties, burning behaviour, use, etc. (Tab. 5). As for things they found interesting, they specified the actual amount of plastics surrounding them and the way plastics burn. Sparking their interest resulted in further questions, e.g. How can plastics harm us? How to prevent the generation of too much plastic waste? The teacher can address these questions during the next lesson. This topic is a part of broader environmental education and these ideas can be used in project work.

4.2.2. Minute card: demonstration in biology

Topic: Circulatory system –blood

The topic selected for this demonstration is perceived as interesting by students (Fig. 1). They have probably heard a lot about blood donation and realize its importance. However, students may have certain misconceptions related to the fact that not everyone can donate their blood to help, no matter how much they want. It is important for the students to perceive the information about blood in the proper context, i.e. how it relates to the circulatory system and human body as a whole. During a discussion about the composition of blood and blood groups, the teacher hands out minute cards.

When students fill them in, the teacher can see whether they understood blood donation and the blood group principles correctly.

Minute card

Name:

Form:

Date:

Thomas decides to donate blood to a person who has been injured in a car crash. This person has B type blood. However, doctors turn Thomas down and tell him that he does not have the correct blood group.

What blood group does Thomas have?

Fig. 1. The minute card is used during a lesson addressing the "Circulatory system – blood" topic (primary school, 7th grade)

Source: Own processing

Students fill in the minute cards, the teacher collects them, and provides students with feedback.

4.2.3. Summary: demonstration in biology

Topic: Fungi

Summary is a tool, which allows the teacher to identify whether students understood the subject matter and whether they can briefly summarise its key points. A demonstration of the Summary filled in by a student during a biology lesson focused on the Fungi topic can be seen in Table 6. The goal was to make students think about why fungi are so important not only in terms of the substance-changing cycle, but also for people.

Student's name:	**Form:**	**Date:**
Describe how fungi get nutrients and how it affects nature and human health.		
Saprophytes get nutrients from dead organisms, reducing agents (decomposers) Parasites get nutrients from living organisms, which is beneficial for the parasite only (ergot fungus), they make moulds Symbiosis: mycorrhiza – mushrooms and tree roots, e.g. Boletus reticulatus – human food Lichens = fungus + algae Pharmaceutical industry – penicillin – antibiotics Food – source of minerals		

Cause mycosis and inflammation
In food industry – yeast (making beer, wine, dairy products, mould-ripened cheese)
Can cause allergy

Table 6. Summary after teaching the "Fungi" topic (secondary school, 1st year)

Source: Own processing

The presented practical demonstrations of the selected formative assessment tools show how students evaluate and describe their own knowledge and skills. As can be seen, the FACTs also indicate what sparks the students' interest because it is connected with everyday life. The answers show how students realize their own learning process and indicate the things they are unsure about. On the other hand, FACTs allow the teacher to identify what the students failed to comprehend and what needs to be revised, the things they find interesting, their misconceptions – and even the teacher's own misconceptions related to the formulation of questions and tasks for the students. Promotion and systematic support of metacognition will help the students throughout their lives. It is a precondition for further education, self-realization, and by extension, their success in the labour market.

5. TRAINING TEACHERS TO PERFORM FORMATIVE ASSESSMENT

Formative activity performed by teachers involves systematic planning of diverse activities for students, which allow for the identification on students' performance and provision of efficient feedback, thus helping them to achieve the determined education goals (Akom 2011; Schildkamp et al. 2020). Teachers identify students' knowledge, their ways of thinking and responses, motivation, and even what it means for students to learn. Formative assessment helps teachers decide what should be taught next and how to do it.

In a class focused on formative assessment, the teacher plays the role of a coordinator. Moreover, they are supposed to prepare activities allowing students to apply the strategies, which can help them understand their own learning process. As a result, students grow more conscious of their own learning process and take more responsibility for it (Elwood & Klenowski 2002; Shore, Wolf & Heritage 2016; Wiliam 2011; Wiliam & Leahy 2015).

Clark (2010) has specified five key principles of formative assessment, which need to be applied in practice:

1. Students must be able to comprehend what they are supposed to learn and what is expected from them.
2. Students need feedback on the quality of their work and what they can do to improve it.
3. In case of need, students must be given advice on how to proceed to improve.
4. Students must be fully involved in deciding about the next steps to be taken.
5. Students must realize there is someone to help them if they need.

Table 7 summarises what the teacher is supposed to realize in terms of formative assessment, and how it affects the next steps they take in teaching (Ganajová et al. 2022).

Teacher realizes that...	**Teacher performs a teaching intervention in order to...**
students learn more efficiently if they know and understand the educational objective	make their planning more precise communicate the educational objectives in a way comprehensible tothe students determine precise criteria necessary for the students to meet to succeed
to facilitate success for all students, it is necessary to identify the point at which each of them is on the path towards the educational goal	constantly collect information about student learning, observe students and adapt teaching during the classes as appropriate
efficient feedback provides specific ideas on how to help students achieve the educational goals	provide focused and constructive feedback develop a set of feedback-provision strategies
one of the most important abilities that can be taught to students is to regulate their own learning	teach students how to assess themselves create rubrics, checklists, metacognitive tools, and other assessment tools as an integral part of students‘ activities before, during, and after learning
meaningful learning requires communication and idea sharing during discussions in which students come up with their own efficient solution proposals	encourage students to learn from each other plan and ask thoughtful questions facilitating the collection of information about student learning
motivation is something that can be developed in students, however, the teacher has to support them	harmonise appropriate level of challenges and equal support for all students purposefully create educational opportunities in which students can realize what they are doing well and what should be improved to maximise their success

Table 7. What needs to be identified in terms of FA implementation and what steps should be taken by the teacher based on these findings

Source: Ganajová et al. 2022

Every formative assessment system requires the teacher to develop a clear idea of the goals to be achieved by their students and the teaching procedures improving student performance.

6. DIGITAL TOOLS USEFUL IN FORMATIVE ASSESSMENT

Digital tools allow for better understanding of student learning and in turn, predict and adapt the learning processes. It also promotes students’ choices to learn “anytime and anywhere” by providing them with self-assessment and peer-assessment opportunities, which helps students determine their own goals and learning strategies (Looney 2019).

The assessment should be based on exactly obtained information, where digital tools can significantly streamline the whole process (Ftáčnik, Šveda & Kireš 2020).

There are a number of digital tools useful in FA, which allow for the creation of questions and collection of student answers, e.g. Kahoot!, Socrative, Polleverywhere, Mentimeter, etc.

Kahoot! is a game-based digital tool. To create and manage the existing quizzes (kahoots), teachers need to register at https://kahoot.com/. Students login to https://kahoot.it or use the Kahoot! application installed on their tablets or smartphones.

Kahoot! can be used to implement the following FACTs:

- before and after – students choose between true and false,
- voting questions, self-assessment card, rubric, checklist – students choose a single answer from the list.

An example of a self-assessment card on the topic of Neutralisation can be seen below. It was given to 8th grade primary school students at the end of a lesson.

The system generates an overview of student answers after each question (Fig. 2). This overview is useful not only for students, but also for the teacher who can identify what students can already manage on their own and what needs more attention. The teacher can respond to this information immediately during the class discussion and modify further teaching accordingly.

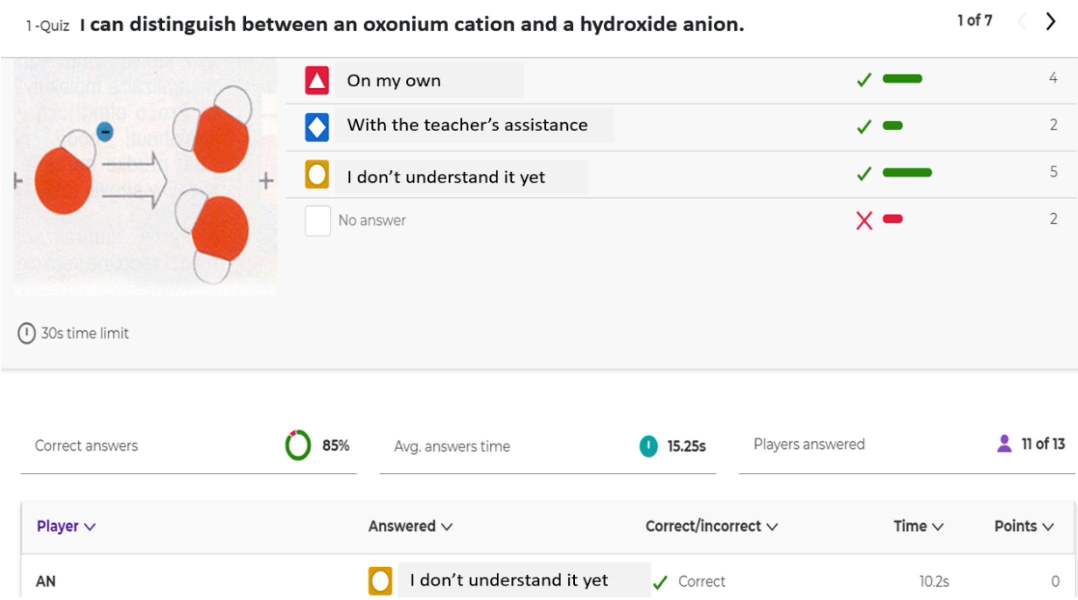

Fig. 2. Evaluation of a selected question from the self-assessment card on the topic of Neutralisation (primary school, 8th grade)

Source: Own processing

A quiz is essentially a FACT. The system processes overall quiz results which can be found in the Reports tab. The teacher can also see how students answered individual questions or how a specific student fared in the quiz. All results can be downloaded as well-arranged spreadsheets.

Socrative can also be used as a voting tool in FA. Figure 3 shows examples of questions in a prediction card on the topic of Microorganisms living with humans for 6th grade primary school students.

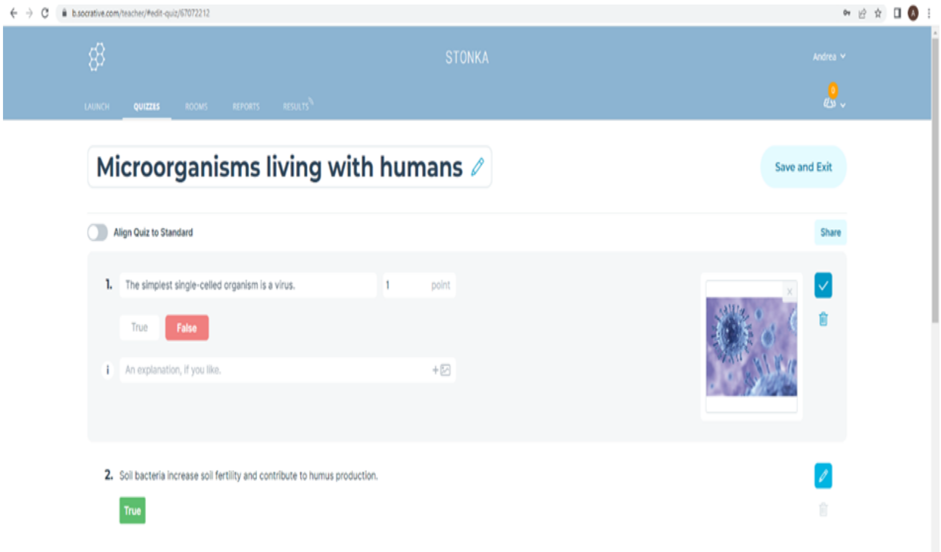

Fig. 3. Question (true/false) for the prediction card on the topic of Microorganisms living with humans (primary school, 6th grade)

Source: Own processing

7. CONCLUSIONS

Formative assessment in teaching and specifically self-assessment activities teach students how to perform self-assessment, peer-assessment, and assess their surroundings in general. Teaching this ability is one of the most important tasks of contemporary and future schools.

However, Slovakia is still waiting for systematic and careful implementation of formative assessment in teaching. To facilitate FA implementation in Slovak schools, a support system for teachers focused on FA and its classroom use need to be created. Such system must include methodological guidelines, digital libraries of formative assessment tools (for specific academic subjects) as well as good practice examples. The demonstrations of FACTs and their implementation in teaching science (biology, chemistry, physics) and mathematics were presented with this goal in mind.

Digital assessment can also help students identify their own strong points and provide them with a more authentic experience with assessment. Digital FACTs provide a number of benefits for both teachers and students, e.g. instant feedback for the teacher based on student answers, faster and more comfortable digital data processing (e.g. automated generation of complex overviews, answer archivation).

Last but not least, for successful FA implementation into the everyday practice, teachers need appropriate support on the level of education policy (investments into professional teacher development and training of future teachers, mentoring, peer support, and formative assessment research).

ACKNOWLEDGMENTS

This contribution was supported by the KEGA No. 004UPJŠ-4/2020 “Creation, Implementation, and Verification of the Efficiency of Digital Library with the Formative Assessment Tools for Science, Mathematics, and Informatics at Primary Schools” grant.

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