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INTEGRATION OF CHILDREN WITH SPECIAL NEEDS IN MATHEMATICS THROUGH VIRTUAL REALITY

Thomas Keller, Andreas Hebeisen and Elke Brucker-Kley
Zurich University of Applied Sciences, School of Management and Law
St.-Georgen-Platz 2, 8401 Winterthur, Switzerland

ABSTRACT

Students with special needs in mathematics lessons can be specifically supported through virtual reality (VR) if they are offered virtual learning environments that offer real benefits through their implementation in VR. In addition to learning by doing, the visualization of mathematical facts in 3D for the training of imagination can offer added value in relation to the tasks themselves or that content can be experienced in class for which this is otherwise not simply possible. The evaluation of the developed learning environments with learners has shown that possible advantages of an immersive learning environment compared to classical teaching aids can be a positive effect on motivation, concentration and learning success.

KEYWORDS

Virtual Reality, Education, Integration of Children with Special Needs

1. INTRODUCTION

The possibilities and benefits of the use of new media in teaching at elementary schools have been discussed for some time. In the context of computer use in schools, the terms media pedagogy and media didactics are often used (cf. (Krauthausen 2012), p. 1). In the context of the present work, however, "new media" primarily means the use of so-called learning or exercise programs. With the use of IT resources, specific knowledge can be imparted in many subjects. New teaching concepts are possible. Especially VR and augmented reality (AR) bring completely new possibilities into the classroom. Simple examples are Google Expeditions and the Google Cardboard. A study by Samsung in Germany in 2017 shows: "More than three-quarters of teachers (79%) agree with the statement that thanks to VR, students have the opportunity to make experiences that they would never otherwise have. […] In addition, the majority of teachers believe that the use of VR in class can increase the motivation of students (74%) and improve their learning success (62%). According to the teachers (58%), the use of the technology can also help in understanding learning concepts. The greatest potential benefits of VR are attributed to the subjects geography/geography (80%), history (74%) and science (62%)" ((Samsung Studie: Lehrer Sehen Großes Potenzial Für Die Nutzung von Virtual Reality Im Unterricht 2017)).

Interestingly, however, digital media are only used hesitantly in elementary schools. There may be many reasons for this. On the one hand, on the side of teachers, on the other hand in pedagogy and in very new media such as virtual reality, the lack of pedagogical content for use in the classroom.

What Confucius (551-479 B.C.) already knew still applies to today's school teaching: "Tell me, and I will forget. Show me, and I may remember. Involve me, and I will understand." This guideline is not only perfectly suited to the topic of virtual reality, it is also often quoted in connection with competence-oriented learning in the context of Lehrplan 21 (d-edk 2016) (Swiss curriculum for primary and secondary schools), where the focus is on the actions of learners. The aim of this work is therefore to develop and implement concrete learning units for mathematical learning in VR that exhibit a degree of interaction that comes close to doing in the sense of Confucius. The learning units are to be designed with a mathematical-didactic view in the context of integration of children with special needs into regular schools. Integration of children with special needs into regular schools often focuses on students with learning difficulties. In the context of this work, however, the term should be viewed holistically and potential for students with special talents should also be pointed out.

2. STATE-OF-THE-ART

In the following, important principles and guiding ideas of integration of children with special needs into regular schools as well as mathematics didactics are examined in order to subsequently deal with immersive learning in the context of VR.

2.1 Integration of Children with Special Needs into Regular Schools

"Less efficient learners bring with them serious deficits from primary education due to cumulative backlogs, so that performance heterogeneity at lower secondary level is particularly high and will increase" ((Affolter and Walt 2017), p. 6).

According to ((Affolter and Walt 2017), p. 7), teaching and learning processes must be arranged in such a way that learners are cognitively activated, i.e. stimulated to think. Good means of doing this is to encourage learners to discover, analyse, justify and explain. "While the learners work on the assignments, the teacher actively observes their learning activities. The teacher deals with the learners, talks to them and asks them for insights into their ways of thinking and strategies. Because a look at learning outcomes alone often offers too little information to identify any misconceptions and make them manageable" ((Affolter and Walt 2017), p. 7).

The integration consciously involves children and young people with disabilities in the regular school and ensures specific support through appropriate measures. Inclusion means that the school accepts all students from its perimeter. It focuses its offer on possible impairments and special needs (cf. (Eckhart 2016), p. 16 f.). According to Schaumburg ((Schaumburg 2015), p. 65), the basic aim is to adapt the lessons to the individual learning requirements of the students. Since the adoption of the UN Convention on the Rights of Persons with Disabilities in 2008, the focus has once again been on the ideal of inclusive teaching, as it focuses on the heterogeneity of pupils as a central principle on which all didactic considerations must be oriented.

2.2 Didactics of Mathematics

Krauthausen ((Krauthausen 2012), p. 3 f.) criticises the fact that computer-assisted learning programs in mathematics that are well-known and widespread on the market today pay too little attention to the current state of research and knowledge in mathematics didactics. The focus is too much on technology instead of content (the subject-specific content) and the programs thus contribute much to the media competence of learners but little to mathematics skills.

Burrill ((Burrill 2017), p. 316) mentions mathematical accuracy (fidelity) and user experience as central mathematics didactic principles. The mathematical accuracy means that the software should always be mathematically correct, the user experience should not hinder the work with the mathematical task and should promote mathematical thinking.

Learners need to be able to make decisions to expand their thinking. This possibility is also closely related to the complexity of a task, which does not necessarily require complex mathematical requirements (cf. (Geiger 2017), p. 289). According to Joubert ((Joubert 2017), p. 20 ff.), while working on a mathematical task, students use means from the so-called "Modes of Production". These include acting (usually in the sense of indicating a solution), formulating (developing hypotheses, solution strategies, etc.) and validating (checking based on evidence, theorems or explanations). Formulation and validation almost always have to be initiated by the teacher.

For the motivation of learners, mathematics itself should increasingly be presented in a way that makes them exciting and captivating themselves, rather than motivating them with other means in the learning programs (cf. (Krauthausen 2012), p. 20): "Effective learning processes are characterized by a high degree of motivation and joy, which however arise from the matter and not from its packaging" ((Krauthausen 2012), p. 21).

Mathematical learning is an important pedagogical task. Mathematical tasks are intended to encourage learners to do something mathematical and thus experience mathematics in the broadest sense (cf. (Joubert 2017), p. 4). All tasks should always contain pragmatic and epistemological aspects. The epistemological aspects refer to the insights to be conveyed to learners while working on a task (cf. (Sinclair and Zazkis

2017), p. 177), whereby the pragmatic value of a task is almost always equated with solving the task (cf. (Sinclair and Zazkis 2017), p. 190). Laborde ((Laborde 2011), p. 82) supplements cognitive aspects (what kind of learning the task triggers in the learner at the current state of knowledge), didactic aspects (with what means the task is set) and instrumental aspects (which instruments the learner needs to solve the task).

2.3 Immersive Learning

Learning in virtual worlds is often called "immersive learning". According to Höntzsch et al. ((Höntzsch et al. 2013), p. 3), immersion describes the degree to which individuals perceive that they interact more with their virtual than with their real environment (individual sense of being there). In a virtual reality, immersion seems to be determined by the degree of representation of the learners, their presence and their possibilities of interaction.

Höntzsch et al. ((Höntzsch et al. 2013), p. 3) describe with reference to Burdea and Coiffet ((Burdea and Coiffet 2003), p. 3) the three "I" of learning with virtual realities: Imagination, immersion and interaction. "Imagination describes the imaginative power of learners to put themselves in the position of a simulation. Real-time visualizations and reactions of the system provide users with immediate feedback on their inputs (interaction). The information is also recorded multimodally [...], i.e. with several senses. This creates a feeling of immersion, i.e. of being directly involved in the simulated world" ((Höntzsch et al. 2013), p. 3). Imagination, immersion and interaction seem to be important factors for immersive learning.

With regard to pedagogy, Geiger ((Geiger 2017), p. 288 f.) points out in the context of mathematics how eminently important it is to select, adapt and implement the tasks in the learning environments. In this context, he points out the importance of cooperation between teachers and researchers in order to anchor well-designed tasks with pedagogically correct approaches in the learning environments and thus improve learning.

A sufficient degree of challenge is important for the learning process (cf. (Geiger 2017), p. 289). Höntzsch et al. ((Höntzsch et al. 2013), p. 4) list the following measures as necessary to avoid overburdening learners in immersive learning environments:

- clear learning objectives, work orders and instructions,
- permanently available background information,
- hints and exercises that stimulate reflection (for example, setting a specific state of the simulation)

Höntzsch et al. ((Höntzsch et al. 2013), p. 3) list the possible support of immersion on learning processes in connection with flow and presence experience as a thesis when using three-dimensional virtual worlds. However, with reference to Grunewald (2009), they point out that these effects are also mentioned in the context of computer game addiction. Chen ((Chen 2016), p. 644) also shows a positive effect on the learning (in the context of language learning) of such environments.

According to Höntzsch et al. ((Höntzsch et al. 2013), p. 4), discovering learning leads to an expansion of personal experience space and to the generation and examination of hypotheses, since knowledge in these learning environments is not predetermined but explorative. It is pointed out that the learning environments must be simulated as truthfully as possible in order for the findings to be successfully transferred into reality. It also describes advantages in the depth of information processing, learning success and motivation, the latter not per se resulting in a higher quality or quantity of cognitive processing and skill acquisition.

3. INTRODUCTION OF THE LEARNING UNITS

The following three learning environments from the "mathbuch IF" (Affolter and Walt 2017) were selected for implementation in VR. The selection was based on interviews with teachers and taking into account the characteristics of a VR environment.

For all virtual learning environments there are the roles learner (works with the virtual learning environment), supervisor (also "coach"), supports learners with errors and problems and asks them to discover, analyse, justify and explain as well as the virtual learning environment (system). The concept is based on the "Game Design Outline" according to Olbrish ((Olbrish 2014), p. 51).

The learning environments are accessible at http://neuelehrkonzepte.ch/ for HTC Vive.

3.1 Virtual Learning Environment 1: Introduction to Virtual Reality

The first virtual learning environment serves to introduce learners to virtual reality. The virtual reality is to be experienced for the first time and the basic operating concepts for the other learning environments are to be learned. This should be done to a degree that allows learners to concentrate fully on the task in the subsequent learning environments and not be distracted because of the controls.

At the beginning, various geometric bodies are stacked on a glass shelf a few meters away. The first task is displayed with a text in the room: The learner must teleport to the shopping cart and slider using the controller. Once there, you can change your position by walking around in real space. The next task is displayed: The objects should become accessible by tilting the tray using the slider. The handle of the slider can be gripped and moved for this purpose. As soon as an angle of approx. 45° is reached, all objects fall to the floor or onto the table and the next subtask, collecting all objects and placing them in the shopping cart, is displayed. Once all items have been placed in the shopping cart, the task can be completed by selecting the button that is now displayed ("Done"). The learner remains in the virtual room and discusses the developed solution and the learned operating elements with the supervisor in virtual reality.

3.2 Virtual Learning Environment 2: Base Area Times Height

Virtual reality should make it possible "that learners know units of length, area and space with the corresponding support concepts" ((Affolter and Walt 2017), p. 175). The learning unit should be "built up experimentally and action-oriented, in that the learners can get to know different models of prisms and cylinders" ((Affolter and Walt 2017), p. 175) in virtual reality and interact with them. "The learners gain so many basic geometric experiences and train their spatial perception" ((Affolter and Walt 2017), p. 175).

The starting position in the learning environment is close to the table. On the table is a geometric body (a cube), whose volume can be calculated by means of base area times height. The first task is to achieve a volume of 1000 cm^3 for the cube. This can be achieved by changing the side length with a slider. If the solution is correct, after a short delay (to prevent random solutions) the next body appears on the table (lying on the surface). As an intermediate task, this body's base must now be placed on the table, as this often causes problems for the learners. When the body is on its base, the sliders for base area and height are displayed and a volume of 1000 cm^3 can be achieved again. Subsequently, the subtasks are repeated for the remaining three bodies.

The difficulty of the subtasks is increased in three steps: The first body is the cube for which only the side length can be changed by a slider. For the next three bodies (circular cylinder, triangular prism, hexagonal prism) a slider is available for the base area and the height. This corresponds to the focus of the task and is therefore realized for the majority of bodies. The cuboid as the last body can be changed individually in three dimensions. The base area can therefore be specifically set with width and length. Since a volume of exactly 1000 cm3 cannot be achieved for the three middle bodies (circular cylinder, triangular prism, hexagonal prism) with steps of exactly 1 cm for base area and height, a tolerance of a few cubic centimeters is provided. This tolerance was increased from 3 to 30 cm in two steps. The reasons for this were not to demotivate the learners with their tendency to perfection if they make an effort but still cannot find a solution, as well as the solubility of the task in practice. The circle number Pi is simplified with the value 3, as is often common for use in integration of children with special needs into regular schools.

If the volume for the cuboid (for this exactly 1000 cm^3) was also reached correctly, a button appears to leave the learning environment. The learner remains in the virtual room and discusses the solution with the teacher. The solution for all subtasks must also be explained in consultation with the supervisor.

3.3 Virtual Learning Environment 3: So Small! So Big!

"Dealing with sizes and masses is very demanding for many learners. Lack of sizing [...] and insufficient knowledge of kilo-, deci-, centi-, milli- and the relationships between units of measurement (e.g. 1 kg = 1000g) are also not rare at secondary level" (Affolter and Walt 2017). It is precisely at these points that the virtual learning environment is intended to build on and provide learners with opportunities to compare sizes: "What is e.g., heavier, shorter, higher, has less content? " (Affolter and Walt 2017).

In order to enhance the learning effect and immersion, the learning environment must be realized with extensive possibilities for interaction with objects and sizes. This learning environment consists of four scenes.

Scene 1: In the start menu you can select from a series of different units of measurement and start the respective scene by selecting one of the buttons. The principle for the individual scenes is identical.

Scene 2 is described using the task for the measure of capacity. However, this is realized identically for the other units of measurement. Six objects of different sizes are displayed in random order (e.g. a cube of 1 m^3 filled with water, an aquarium, a trophy). However, these are all displayed in the same size. The appropriate unit of measurement (e.g. hectoliter for the aquarium) must now be assigned to each object from the position panel. If a unit of measurement has been assigned to each object, the button for displaying the solution becomes active. If the solution is requested, the objects are sorted according to the place value chart and displayed in their original size. The different sizes make misconceptions immediately apparent to learners. In addition, a reference of the sizes to suitable objects can be produced in original size.

Scene 3 for learning assurance is similar in structure to scene 2. Six objects are displayed. This time, however, not only the appropriate unit of measurement but also the appropriate dimension and a ratio factor must be assigned.

As scene 4, a task for sorting objects according to size, weight, etc. is optionally implemented. Six objects are displayed in random order (optically identically large). Instead of assigning units of measurement, the objects must be sorted by size (or weight, etc.) using buttons. If the solution is activated, the order is retained, but the objects are displayed in real size.

4. RESULTS

In order to gain further insights into the learning environments developed, these were played through at four different schools in the form of a controlled experiment with 20 learners with special needs after completion of development. The objectives, structure and results of this evaluation are described below.

The aim of the evaluation is not a scientific study on the measurement of impact. Primarily, factors such as the fun or motivation of the students to learn in a virtual environment, the learners' personal feelings about learning success, the didactic correctness and the quality of the implementation (especially usability) of the learning units themselves should be evaluated. In this way, a first indicator of possible effectiveness and the potential for improvements in learning environments is to be shown.

4.1 Choice of Sample

In mathematics lessons in particular, diagnoses for isolated learning disorders (dyscalculia) are no longer often issued. Instead, there is talk of a partial weakness in mathematics. Discussions with the teachers of the selected schools have shown that the idea of inclusion by Eckhart ((Eckhart 2016)) has been lived here for about a year and that the affected learners have been integrated into regular classes. The lessons are therefore distributed to the system and not to individual students. As a result, the field for the evaluation was opened a little bit. Students with special needs in mathematics were selected as participants, but who do not necessarily (diagnosed) suffer from an isolated learning disorder. The decision as to who would participate in the evaluation was made by the teachers. Table 1 shows the number of participants by class and gender.

Table 1. Summary of participants

Class	Age	Sex	Number
7	13–15	female	1
		male	7
8	14–16	female	3
		male	3
9	15	female	1
		male	5
Total number of participants			**20**

4.2 Procedure

The evaluation sessions at one school lasted between half a day and a full day (depending on the number of participants and other interested parties). If possible, a room was reserved for the entire duration of the evaluation and the test set-up started approximately one hour before the start of the evaluation. This consists of a complete PC system with sufficient graphic performance including a screen for observation by the supervisor and the "HTC Vive" system consisting of Head-Mounted Display (HMD, "glasses"), the two controllers and the base stations (also "Lighthouses") for tracking. For details on the technical operation and installation of the system, refer to the "HTC Vive" manual.

The learners were taken out of class individually or in pairs and completed the various learning environments in a maximum of 45 minutes. Before entering the virtual world, the instructions including rules and rights were discussed and the most important operating elements explained. The coaching during the stay in the virtual learning environments was also carried out by the author as a supervisor.

Finally, all learners completed an anonymous questionnaire for the evaluation.

4.3 Survey Results

The questionnaire with 24 questions was submitted to the learners on paper. For three questions a text answer is expected, 21 questions contain a scale on which the degree of approval is marked. Questions 1 and 2 ask about the previous experience with virtual reality and video games. Questions 3 to 5 examine the operation and clarity of the tasks. The learning environments 2 and 3 are evaluated more precisely with questions 6 to 14 (some questions appear duplicated because they refer to learning unit 2 and 3). The introduction is not addressed with specific questions, as it is not the main focus of the evaluation and to keep the questionnaire short. The remaining 10 questions deal with the general learning experience.

Table 2. Compilation of survey results

				Learning unit 1	Learning unit 2	Learning unit 3a	Learning unit 3b	Do you have already experience with VR?		How often are you gaming?		How easy was the user interface to learn?		How clear were the tasks?		How much were you dependent on the support of the supervisor (coaching)?		How well known were the tasks? Have you already solved similar tasks?		How much did you like the learning environment?		How difficult were the tasks for you? (inverse scale)		How did you solve your tasks?		How much did you like the learning environment?	
#	Age	Class	Sex	VLU1	VLU2	VLU3	VLU3	1.		2.		3.		4.		5.		6.		7.		8.!		9.		10.	
1	15	9	male	X		X	X	0,0	0,0%	9,9	64,7%	14,8	96,7%	15,3	100,0%	0,0	0,0%	14,6	95,4%							15,3	100,0%
2	14	8	male	X		X	X	0,2	1,3%	10,6	69,3%	7,6	49,7%	14,9	97,4%	7,5	49,0%	7,7	50,3%							14,9	97,4%
3	15	9	male	X	X	X	X	0,2	1,3%	2,6	17,0%	13,9	90,8%	14,9	97,4%	10,2	66,7%	14,7	96,1%	14,2	92,8%	1,7	11,1%	7,2	47,1%	13,9	90,8%
4	15	9	female	X	X	X	X	0,0	0,0%	0,0	0,0%	7,4	49,0%	14,3	94,7%	7,2	47,7%	7,5	49,7%	13,2	87,4%	10,0	66,2%	8,7	57,6%	11,9	78,8%
5	15	8	female	X	X	X	X	0,2	1,3%	4,1	27,2%	11,1	73,5%	12,9	85,4%	7,6	50,3%	14,2	94,0%	12,4	82,1%			5,5	36,4%	11,0	72,8%
6	14	8	male	X	X	X	X	7,5	49,7%	8,0	53,0%	12,7	84,1%	4,1	27,2%	7,5	49,7%	7,7	51,0%	9,2	60,9%	3,9	25,8%	5,3	35,1%	8,7	57,6%
7	15	9	male	X	X	X	X	0,0	0,0%	9,6	63,6%	12,6	83,4%	11,3	74,8%	6,5	43,0%	6,4	42,4%	11,4	75,5%	1,7	11,3%	11,8	78,1%	10,2	67,5%
8	15	9	male	X	X	X	X	7,5	49,7%			7,5	49,7%	11,6	76,8%	9,7	64,2%	0,0	0,0%	11,3	74,8%	2,4	15,9%	15,0	99,3%	11,3	74,8%
9	15	9	male	X		X	X	7,5	49,7%	5,6	37,1%	13,8	91,4%	15,1	100,0%	11,2	74,2%	15,1	100,0%							12,1	80,1%
10	13	7	female	X	X	X	X	7,0	48,3%	5,6	38,6%	12,7	87,6%	7,2	49,7%	7,2	49,7%	7,2	49,7%	14,5	100,0%	6,3	43,4%	9,3	64,1%	14,5	100,0%
11	13	7	male	X	X	X	X	0,0	0,0%	11,8	81,4%	8,7	60,0%	14,5	100,0%	3,6	24,8%	6,6	45,5%	13,0	89,7%	5,1	35,2%	11,2	77,2%	13,1	90,3%
12	13	7	male	X	X	X	X	7,2	49,7%	11,7	80,7%	14,3	98,6%	14,4	99,3%	7,4	51,0%	10,3	71,0%	8,1	55,9%	6,1	42,1%	11,1	76,6%	14,3	98,6%
13	14	8	female	X	X	X	X	0,0	0,0%	10,1	69,7%	7,2	49,7%	10,5	72,4%	7,2	49,7%	9,7	66,9%	11,5	79,3%	6,2	42,8%	9,8	67,6%	8,8	60,7%
14	16	8	male	X			X	6,2	42,8%	1,4	9,7%	6,1	42,1%	7,0	48,3%	6,8	46,9%	7,7	53,1%							11,5	79,3%
15	15	8	female	X	X	X	X	0,0	0,0%	2,1	14,5%	10,0	69,0%	13,9	95,9%	7,4	51,0%	10,5	72,4%	8,8	60,7%	7,8	53,8%	0,0	0,0%	6,4	44,1%
16	14	7	male	X	X	X	X	14,1	97,2%	5,6	38,6%	11,2	77,2%	13,9	95,9%			0,7	4,8%	11,7	80,7%	3,5	24,1%			11,8	81,4%
17	13	7	male	X	X	X	X	6,1	42,1%	4,1	28,3%	8,4	57,9%	7,2	49,7%	7,3	50,3%	13,9	95,9%	11,5	79,3%	3,5	24,1%	14,3	98,6%	11,6	80,0%
18	15	7	male	X	X	X	X	1,3	9,0%	10,1	69,7%	11,3	77,9%	11,8	81,4%	8,3	57,2%	14,1	97,2%	13,7	94,5%	3,8	26,2%	8,9	61,4%	14,2	97,9%
19	13	7	male	X	X	X	X	0,2	1,4%	2,3	15,9%	13,8	95,2%	14,1	97,2%	9,0	62,1%	9,5	65,5%	13,0	89,7%	0,3	2,1%	10,5	72,4%	13,1	90,3%
20	13	7	male	X	X	X	X	3,0	20,7%	7,4	51,0%	14,5	100,0%	9,9	68,3%	9,5	65,5%	11,4	78,6%	14,3	98,6%	1,0	6,9%	7,2	49,7%	12,4	85,5%
N									20		19		20		20		19		20		16		15		15		20
Max									97,2%		81,4%		100,0%		100,0%		74,2%		100,0%		100,0%		66,2%		99,3%		100,0%
Min									0,0%		0,0%		42,1%		27,2%		0,0%		0,0%		55,9%		2,1%		0,0%		44,1%
Average									23,2%		43,7%		74,2%		80,6%		50,2%		64,0%		81,4%		28,7%		61,4%		81,4%
Median									5,2%		38,6%		77,6%		90,1%		50,3%		66,2%		81,4%		25,8%		64,1%		80,8%
Variance									7,9%		6,5%		3,8%		4,8%		2,6%		8,4%		1,8%		3,4%		6,6%		2,4%
Standard deviation									28,1%		25,6%		19,4%		21,9%		16,2%		29,0%		13,4%		18,3%		25,6%		15,4%

	How difficult were the tasks for you? (inverse scale)		Did you know the "Stellentafel" before?		How easily did you recognize the objects?		How much did it help you to see the items in full size to imagine the sizes?		How was it for you in the virtual environment? (inverse scale)		How concentrated were you in the virtual environment compared to normal lessons?		How well could you concentrate on the instructions of the supervisor?		Wie sehr hat sich das Lernen nach Schule angefühlt?		Did the awards in the main menu motivate you to solve further tasks or to repeat a task?		How much do you think you have learned?		Would you like to have classes in virtual reality again?	
#	11.!		12.		13.		14.		15.!		16.		17.		18.		19.		20.		21.	
1	6,2	40,5%	12,3	80,4%	11,5	75,2%	7,5	49,0%	0,0	0,0%	10,3	67,3%	15,3	100,0%	5,5	35,9%	10,5	68,6%	11,5	75,2%	13,1	85,6%
2	6,7	43,8%	7,2	47,1%	12,6	82,4%	11,8	77,1%	0,2	1,3%	12,6	82,4%	14,7	96,1%	0,6	3,9%	7,3	47,7%	4,2	27,5%	14,9	97,4%
3	2,0	13,1%	12,4	81,0%	12,4	81,0%	15,3	100,0%	0,0	0,0%	15,2	99,3%	12,3	80,4%	3,0	19,6%	15,3	100,0%	11,4	74,5%	15,3	100,0%
4	7,1	47,0%	12,8	84,8%	11,0	72,8%	13,4	88,7%	4,1	27,2%	12,5	82,8%	12,5	82,8%	5,4	35,8%	13,8	91,4%	10,7	70,9%	11,7	77,5%
5	6,8	45,0%	1,2	7,9%	11,1	73,5%	14,0	92,7%	5,0	33,1%	11,5	76,2%	12,2	80,8%	12,9	85,4%	11,7	77,5%	10,4	68,9%	12,3	81,5%
6	3,8	25,2%	11,2	74,2%	5,6	37,1%	13,2	87,4%	1,3	8,6%	11,0	72,8%	12,0	79,5%	13,0	86,1%	10,6	70,2%	7,7	51,0%	14,7	97,4%
7	2,6	17,2%	0,6	4,0%	14,5	96,0%	7,1	47,0%	6,5	43,0%	7,1	47,0%	13,3	88,1%	11,3	74,8%	13,0	86,1%	10,1	66,9%	13,9	92,1%
8	2,4	15,9%	15,0	99,3%	11,3	74,8%	15,1	100,0%	10,2	67,5%	0,0	0,0%	14,9	98,7%	3,5	23,2%	13,6	90,1%	7,5	49,7%	11,5	76,2%
9	2,1	13,9%	13,8	91,4%	14,4	95,4%	14,8	98,0%	3,5	23,2%	4,1	27,2%	12,1	80,1%	8,2	54,3%	12,3	81,5%	3,0	19,9%	12,5	82,8%
10	6,3	43,4%	6,6	45,5%	7,1	49,0%	10,7	73,8%	0,0	0,0%	14,5	100,0%	11,2	77,2%	11,5	79,3%	14,5	100,0%	10,6	73,1%	14,4	99,3%
11	6,2	42,8%	0,1	0,7%	7,8	53,8%	10,2	70,3%	7,2	49,7%	14,4	99,3%	14,5	100,0%	5,6	38,6%	12,8	88,3%	6,8	46,9%	14,5	100,0%
12	3,9	26,9%	10,9	75,2%	14,3	98,6%	10,7	73,8%	0,4	2,8%	13,5	93,1%	14,3	98,6%	7,0	48,3%	14,4	99,3%	8,0	55,2%	14,5	100,0%
13	6,2	42,8%	6,8	46,9%	10,7	73,8%	9,5	65,5%	6,3	43,4%	12,7	87,6%	6,8	46,9%	12,5	86,2%	9,3	64,1%	9,4	64,8%	14,5	100,0%
14	6,2	42,8%	13,3	91,7%	7,4	51,0%	13,3	91,7%	0,4	2,8%	13,3	91,7%	13,1	90,3%	13,3	91,7%	13,6	93,8%	13,9	95,9%	13,1	90,3%
15	4,9	33,8%	12,5	86,2%	14,5	100,0%	11,4	78,6%	0,0	0,0%	12,2	84,1%	12,5	86,2%	2,5	17,2%	6,9	47,6%	8,4	57,9%	14,5	100,0%
16	3,9	26,9%			13,7	94,5%	13,8	95,2%	0,5	3,4%	13,5	93,1%	14,0	96,6%	13,8	95,2%	7,2	49,7%	14,1	97,2%	14,0	96,6%
17	3,5	24,1%	13,5	93,1%	13,6	93,8%	6,7	46,2%	0,2	1,4%	14,3	98,6%	10,8	74,5%	6,9	47,6%	7,0	48,3%	9,5	65,5%	14,3	98,6%
18	6,1	42,1%	8,4	57,9%	8,4	57,9%	6,7	46,2%	0,2	1,4%	13,0	89,7%	12,1	83,4%	3,0	20,7%	11,2	77,2%	10,2	70,3%	14,0	96,6%
19	1,3	9,0%	13,2	91,0%	13,7	94,5%	10,1	69,7%	0,3	2,1%	12,4	85,5%	8,5	58,6%	12,8	88,3%	0,6	4,1%	12,3	84,8%	13,4	92,4%
20	0,1	0,7%	6,6	45,5%	10,0	69,0%	10,2	70,3%	0,3	2,1%	13,8	95,2%	11,6	80,0%	13,4	92,4%	13,9	95,9%	10,8	74,5%	14,4	99,3%
N		20		19		20		20		20		20		20		20		20		20		20
Max		47,0%		99,3%		100,0%		100,0%		67,5%		100,0%		100,0%		95,2%		100,0%		97,2%		100,0%
Min		0,7%		0,7%		37,1%		46,2%		0,0%		0,0%		46,9%		3,9%		4,1%		19,9%		76,2%
Average		29,8%		63,4%		76,2%		76,1%		15,6%		78,6%		83,9%		56,2%		74,1%		64,5%		93,2%
Median		30,3%		75,2%		75,0%		75,5%		2,8%		86,6%		83,1%		51,3%		79,5%		67,9%		97,0%
Variance		2,1%		10,1%		3,5%		3,4%		4,4%		6,8%		1,9%		9,4%		6,1%		3,8%		0,7%
Standard deviation		14,4%		31,7%		18,8%		18,4%		21,0%		26,0%		13,6%		30,7%		24,6%		19,4%		8,1%

5. DISCUSSION

Only two participants stated in question 6 (N=20) that they had never seen the tasks before. According to them, however, this has no noticeable effect on the understanding of the task (cf. question 4) or on the difficulty of the task (cf. questions 8 and 11). The others had already seen the tasks (7), they were familiar with them (5) or very familiar (6). As a result, the majority of the test persons recognized the tasks from the "math book".

For questions 7 and 10, all of them stated that they liked the learning environments up to perfect (median 81.4% and 80.8%, respectively; N=16 and N=20). Almost all of them indicate the level of difficulty (questions 8 and 11) between easy and medium. Only two indicate this (about both questions together) with rather difficult (N=15 and N=20 respectively). The observations have shown that few were able to solve the tasks (especially learning environment 3) directly without having to think and correct their first solution. For learners who have succeeded in doing so, there is a small tendency for them to assess their concentration (Question 16) and their learning success (Question 20) lower.

For learning environment 2 (base area times height), the first two learning and performance goals set out in the concept have been met by all learners from an external perspective: The geometric bodies have been perceived as such virtually and in 3D, they have been interacted with and changed characteristics of the bodies have been visible and tangible for the learners. The aspects of the targeted change of properties in order to achieve the given volume and to recognize under which circumstances the volumes of the bodies are the same, however, could rarely be observed. Although 2 learners state (question 9, N=15) only to calculate, mostly (7) or at least in half (3) to solve the task, experimental solving subjectively outweighed calculating.

The place value chart (question 12, N=19) from virtual learning environment 3 did not know 3 learners according to their statements. The others had already seen it, with a tendency to know it well. This didactic material is therefore also well recognized in its virtual form of presentation. Only 9 immediately recognized the objects (question 13, N=20). The others did not recognize them immediately. According to the observations, this particularly affects the child's 3D models of the lengths (1 m, often thought to be a doll) and the syringe and ink cartridge of the hollow masses (even in original size the difference in size was often not recognized). Replacing or resizing some 3D models could help here. Scales have therefore been added as supporting aids during the implementation.

Seeing the objects in their original size has helped all (mostly a lot) (question 14, N=20). It therefore seems to have succeeded in making it possible to experience orders of magnitude that are difficult to comprehend on paper and to point out errors simply, comprehensibly and impressively.

According to the learners (question 16, N=20), learning in the virtual learning environment has a positive influence on concentration. 3 learners state to have been more concentrated than in class, a full 14 that they have even been very concentrated. The 3 test participants (all from the 9th grade), who stated lower values, had the subjective impression that the tasks were rather too easy for them. This is also confirmed by their answers on the level of difficulty and subjectively perceived learning success. In question 5, many stated that they were dependent on the support of the supervisor. It is therefore also important to know whether they were able to concentrate on their instructions, while at the same time they had to focus on the task and the operation and had quiet music in the background. In answer to question 17 (N=20), 14 say that they were able to concentrate very well on the instructions, 4 state well and 2 that they at least understood some instructions.

What is surprising is the effect of the trophies in the main menu as a minimal form of gamification on the motivation of the learners. This was observed during the evaluation and is also clearly reflected in the questionnaire in the answers to question 19 (N=19) (median 79.5%). Only one person states that the awards hardly motivated him. 10, on the other hand, have been very motivated, 5 also indicate a strong positive influence on motivation and the remaining 4 have at least been somewhat motivated.

With an overwhelmingly high value, all participants state that they would very much like to have lessons in virtual reality again (question 21, N=20, median 97.0%, minimum 76.2%). The positive effect of the new medium on motivation seems to be confirmed. The fact that half of all learners say that learning in the virtual environment felt more than half (or even completely) like school (question 18, N=20), and that everyone claims to have learned something (mostly much, median 67.9%) (question 20, N=20) also points out that the interest in teaching virtual reality is not just an escape from school. The observations confirm the impression of learning success. Many participants seemed to have gained a decisive insight at a certain point in one of the learning environments.

6. CONCLUSION

The positive effect on motivation and possible new experiences mentioned in the literature was confirmed by the evaluation. Almost all learners have worked in a very concentrated manner and state this in the questionnaire. The potential for addiction quickly became apparent during the evaluation. Questions were quickly asked about the possible use of the technology for video games and many stated in the answers to the questionnaire that they already spend a lot of time with video games every day. In the context of the school, contact with questionable content can be largely controlled by a suitable selection. However, a constructive discussion with the learners about addictive behavior and content in private use appears to be sensible and, alongside clear rules of conduct, the only possible means against problematic media behavior.

The learning environments largely follow the principles of immersive learning. Coaching is also considered important for immersive learning. The findings of the evaluation have confirmed this. Most learners say that they were dependent on the support of the supervisor and were able to concentrate on them. According to these data, most of the subjects could be kept in the flow channel (Olbrish 2014) during the evaluation, as the observations also confirm. The correctness of the model can also be guessed by the minor correlation that has been recognized in the answers on task difficulty, concentration and learning success. The positive effect on learning success and motivation mentioned in the literature can be supported. With a few exceptions, all learners indicated a positive learning success in the responses to the questionnaire. Many learners were able to observe how they could expand their personal experience space (eureka moment). However, empirical proof is still lacking.

Ultimately, virtual reality is seen in mathematics as a good complementary tool that can also be used without any problems for children with special needs into regular schools and which gives an idea of its strengths in the area of motivation, concentration and learning success of learners. The actual effect would have to be measured precisely in further studies. Before a broad use of virtual reality is possible at elementary school, the medium must develop further and further tasks must be provided in dialogue with experts from pedagogy.

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