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MONTESSORI APPROACH IN CHEMISTRY TEACHING AT THE LOWER LEVEL OF AN EIGHT-YEAR HIGH SCHOOL: POSSIBILITIES OF IMPLEMENTING SELECTED ELEMENTS IN A CLASSICAL SCHOOL

Michala Opatová[a] and Petr Distler[b,c]

[a] Gymnázium Duhovka, Ortenovo náměstí 1274, 170 00 Prague 7, [b] Department of Teaching and Didactics of Chemistry, Faculty of Science, Charles University, Albertov 6, 128 00 Prague 2, [c] Department of Nuclear Chemistry, Faculty of Nuclear and Physical Engineering, CTU, Břehová 7, 115 19 Prague 1, Czech Republic
petr.distler@natur.cuni.cz

The article presents the concept of teaching chemistry at the Montessori grammar school, including the possible integration of chemistry into the natural sciences class. The goal of the paper is to introduce to teachers elements of Montessori pedagogy that can be implemented in chemistry teaching at classical schools. The described principles are supplemented with examples of specific materials (e.g. StudyGuide, self-assessment, group work assignments), including a summary of the advantages and disadvantages in the implementation of innovations. The next focus is on describing the phases of learning for developing pupils' knowledge and key competencies, individual and group work and providing feedback, working with a heterogeneous group of learners or justifying the sufficient space for practice and learning.

Keywords: Chemistry teaching, Montessori pedagogy, integrated thematic education, heterogeneous grouping

1. Alternative education

Chemistry and the natural sciences in general have long been among the least popular subjects, with chemistry of the first rank[1,2]. This is directly related to the low number of pupils who choose chemistry for further study at high school or university.

Various projects focusing on varied teaching and modern pedagogies try to overcome this handicap. Popular methods of such projects include, for example, the implementation of inquiry-based and project-based learning[3] or the use of ICT[4]. Alongside, there are an increasing number of alternative schools with a different teaching concept and therefore a different way of teaching chemistry. The term alternative comes from the Latin words "*alter*" (different) and "*nativus*" (natural), i.e. a different choice of what is common, classical[5]. The most common types of alternative schools are Dalton, Waldorf, or Montessori. The common features of these trends include the use of activating and comprehensive teaching methods, a focus on the child (pedocentrism) and his all-round development, different assessment of pupils and a different way of organising teaching[6]. It should be recalled that alternative schools registered in the Register of Schools and Educational Establishments are also obliged to teach according to the relevant national Framework Education Programmes (FEP).

2. Montessori pedagogy

Professor Maria Montessori was an Italian anthropologist, physician and educator. She observed children in orphanages and came up with the idea that children can do in kindergarten what they do at home. At the same time, she allowed them to choose the work that interested them at the moment and encouraged them to explore and learn with the teaching aids. This idea is still evident in Montessori schools today, with a teaching environment and a choice of what to do, less dependence on a teacher, more cooperation between pupils, clearly defined rules for work or age mix. Here the teacher is a partner who helps the child to manage everything by himself[6]. Montessori pedagogy is in great demand abroad, but it is no longer unusual to have at least one Montessori kindergarten in a small town, a Montessori school in a larger town or a multi-year Montessori grammar school in Prague; there are 159 Montessori schools in the Czech Republic[7,8].

In this paper, we focus on Montessori education, specifically on the description of chemistry teaching with the aim of sharing the functional elements of the lower grade of the 8-year Czech-English Gymnázium Duhovka, and thus provide inspiration for teachers of classical schools who can implement the selected elements into their lessons. This is in line with the general trend that selected elements of alternative pedagogy are gradually being incorporated into teaching in classical schools.

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3. Educational area *Human and Nature* at the lower level of the eight-year Montessori Gymnázium Duhovka

In the *Fundamentals of Science* (the 1st year), 3 hours per week of biology are taught in the first half of the year and the same number of hours in the second half of the year focusing on geography. The main aim of the *Fundamentals of Science* class is therefore to learn about the topics and then to develop an orientation in the natural environment, to use technical concepts and to try out observation methods in practice. The course usually ends with a fieldwork at the end of the year, where pupils try out practical tasks in nature. Besides this subject, pupils have one physics lesson per week. The aim of the one-hour physics lesson is to introduce a new discipline, and pupils gradually learn to carry out simple experiments, keep a record of laboratory work and use experimentation to describe bodies and processes. Last but not least, Physics in the 1st year serves as a preparation and foundation for *Natural Sciences*. Another aim of this concept is to involve the pupil as actively as possible in the learning process and to delegate responsibility for the learning process to the pupil.

In the 2nd and 3rd year, teaching is done in a mixed group across years. Pupils have 6 hours of *Natural Sciences* and 2 hours of *Geography* per week; selected topics are also taught in English. There are usually 15 pupils in a group, which is equivalent to halved lesson in a mainstream school. At the Gymnázium Duhovka, pupils encounter chemistry in the subject *Natural Sciences* (usually scheduled as 4+2, i.e. four lessons one day and two lessons on another day, exceptionally 2+2+2). Pupils have the opportunity to choose a topic from chemistry, biology and physics once every six weeks during the school year (always two topics per subject), in the second year they choose from the other half of the topics. Thus, each pupil completes all the topics

for the second and third year, but in the order of his/her choice (Table I). In the second and third year (*Natural Sciences*) and the fourth year (*Chemistry*) all the topics are covered and the expected outcomes according to the FEP for Chemistry are met. For teachers, this timing means the possibility of having a coherent intensive block that allows the topic to be covered in more depth in a shorter period of time. The timetable also includes laboratory hours (Gymnázium Duhovka has one laboratory for

teaching chemistry (Fig. 1) and one for teaching physics and biology). Each topic is therefore explored theoretically and practically at the same time.

For example, under the cross-cutting theme Environmental Education, the topics in the first row of Tab. I. emphasizes the interrelationships across subjects. For the topic of photosynthesis, which will be mentioned later, this is an effort to understand the connections and overlaps across subjects, including overlaps such as global warming or food security.

In the sense of a combined approach to the integration of science, in 4th year, science is divided into the subjects of chemistry, biology and physics, which changes the approach to teaching (e.g. a different method of assessment – equal emphasis is placed on knowledge and on continuous work; in the first three years, more emphasis is placed on continuous work by the pupils). During this year, pupils continue with an extension of inorganic and organic chemistry, discuss natural

Table I
Topics in *Natural Sciences*

Chemistry	Biology	Physics
Chemical reactions	Secrets of plants	An electron and a photon on the way to light
Humans and carbohydrogens	Animalia	The ball is on your court
Atoms, come together!	A world in danger	Properties of materials
Periodic table	Change is life	Strength in air and water

Table II
Subjects in the field of Human and Nature

Subject	1st year	2nd year	3rd year	4th year
Fundamentals of Sciences	3	–	–	–
Physics	1	–	–	2
Natural Sciences	–	6	6	–
Geography	–	2	2	–
Chemistry	–	–	–	2
Biology	–	–	–	1

Fig. 1. **Chemistry laboratory**

substances (basics of static biochemistry) and finally the unit 'Chemistry and society'.

The lesson allocations are summarised in Tab. II. According to the FEP, the minimum time allocation for the educational area of "*Human and Nature*" is 20 hours; the available allocations have been increased by an additional five teaching hours at the Gymnázium Duhovka.

4. Teaching chemistry within the subject *Natural Sciences*

You may have asked yourself how it is possible that chemistry lessons in secondary school do not start with the usual topics as they are most often presented in the textbook (e.g. properties of substances, particle composition of substances, etc.), but the pupil may encounter for the first time, for example, the topic "*Chemical reactions*".

Nevertheless, the pupils successfully manage this way of teaching. Prerequisites for success include: (i) Pupils have a carefully prepared learning environment, they know in advance what outcomes are expected of them, what the objectives of the topic are, what they are expected to know, what they are expected to understand; ii) pupils work in a heterogeneous group (second and third year pupils), as a result of which they compare less with each other (compared to working in a purely homogeneous group) and there is peer learning (more experienced thirds initially helping second years), cooperation and feedback; iii) the teacher prepares a motivational introduction for the pupils, giving examples of reactions from everyday life and gradually extending the topic to include technical concepts; during the intensive block, pupils learn to work with the elements of the periodic table, with which they can write simple equations and, most importantly, try out laboratory experiments on reactions.

Project name: **Atoms, come together!**
Subject: *Chemistry* Name: _____
Block: _____ School year: _____ Teacher: _____

Final phase: Evaluation	Final test / 0,5	Final project assessment / 0,6
	Mini test from compounds / 0,2	Portfolio checking / 0,2
	Mini test from elements / 0,2	Other stuff / 0,1–0,2
Group work		

Initial phse of the project		L5: What is the oppoite of acids?	PL5	Final revision	V_5
		L4: Are acids really acidic?	PL4	Experiment within the group work	V_4
		L3: How do oxides form?	PL3	LAB III	V_3
		L2: Wat are halides?	PL2	LAB II	V_2
		L1: How do atoms bond?	PL1	LAB I	V_1
	My space	**Lessons**	**Mandatory tasks**		**Optinal tasks**
			Individual work		

Fig. 2. **Sample StudyGuide for the topic "*Atoms, come together!*"**

The timetable is derived from the StudyGuide, which is available to the student from the beginning of each unit (an example is shown in Fig. 2 for the topic "*Atoms, come together!*"). In the StudyGuide, the learner has a plan of which activities to complete, what he/she can choose as additional (optional) activities to explore the topic in more depth, what laboratory exercises to expect (LAB I-III: volcano, cleaning coins in salt solution, preparation and properties of CO2) and what will be assessed. Each section (line) of the StudyGuide is completed step by step. By completing the sections of the StudyGuide, the learner knows what part of the work/topic he/she has already completed, where he/she is and what is still to come, which helps him/her to organise his/her own learning.

The lesson (new topic) always starts with a lesson (L1 – L5), followed by individual/group work on worksheets, lab work, and optional activities to further practice/expand the material. Choice is also an important principle of Montessori teaching, which strengthens the intrinsic motivation of the pupils. In the StudyGuide you can see five optional activities (last column). The pupils can choose these (they usually do three of the five prepared ones). The aim of these activities is to consolidate the material. This approach, i.e. sufficient emphasis on practising the material, is also promoted by the latest revision of the FEP, which states that pupils often "*do not have sufficient space to acquire the knowledge they have learned, to understand it in context and to apply it in real situations. This leads to pupils failing to really* understand *the material they are learning*"[9]. Another StudyGuide item, *My space,* means that the pupil writes down a question that came to mind during the lesson or concepts they heard about in the presentation. The *Final Phase: Evaluation* indicates what pupils will be graded on and what weight the grade will carry. There is a written test of knowledge, too, which emphasises positive feedback. In the test, correct answers are primarily marked and pupils are given space to work out what the correct answer should have looked like as a part of the analysis of the test. They can re-take the test if they are interested in. Oral testing is not used for a number of reasons (e.g. not involving all pupils, using time for more useful activities, stressful situation for the pupil). Mini tests are important to continuously verify if pupils have understood the material. *Portfolio checking* means whether the pupil has worked out all the compulsory activities, checked them and systematically placed them in the portfolio folders. By other, you can imagine, for example, pupils' activity in class or the completion of homework. In addition to the aforementioned StudyGuide, the portfolio also contains lesson notes, worksheets that the pupil develops at his/her own tempo, protocols and other support materials.

Teachers of *Natural Sciences* have an overview of what is discussed in other blocks in chemistry, biology and physics, so they can remind pupils of cross-curricular issues during the explanation - e.g. to connect reactions of photosynthesis with biology and manifestations of living organisms. At the end of the school year, pupils have a inquiry-research day where they work in heterogeneous groups on a given topic, apply the knowledge and skills they have acquired and present their findings to their classmates and other interested parties in the final third of the day. An example of such a topic is "*How does the colour of food influence our taste?*", in which they combine their knowledge of chemistry and biology in particular and prepare a demonstration of food in unusual colours. The benefit of such an output is both academic – summarising existing knowledge and skills – and social – cooperation, communication or training presentation skills. The outcome at the end of the two years of *Natural Sciences* is also a final test on the topics covered (all subjects, mostly closed questions), and a practical exam (the pupil draws a teacher (and thus his subject), the teacher has various tasks prepared for the pupil (again, the pupil draws a lottery) and develops a task which he then presents orally. This brings the topic unit to conclusion both for the pupil in terms of recapping information and demonstrating laboratory skills, and for the teacher in terms of feedback on what the pupil has learned in the long term. In addition to project-based learning, excursions are also organised for pupils to connect the topics covered (e.g. wastewater treatment plant or Techmania science centre).

5. Phases of learning and recommendations for their successful implementation

Three-phase teaching is typical for teaching (not only) *Natural Sciences:*

i) introductory lesson (explanation);
ii) individual and group work of pupils;
iii) sharing the findings/outcomes and reflection on the work.

Phase 1: Introductory lesson (explanation)

After the familiarity with the objectives of the lesson/ block, an introduction to the topic is given by the teacher in a frontal way to transfer knowledge and principles (the so- called lesson, marked with the letter L in Fig. II, e.g. *L1 How do atoms bond?*). The titles of the lessons are usually formulated with a question to get the pupil thinking about a possible answer already in the introduction, or the questions can be used the following lesson for review. The lesson usually lasts within 15 and 20 minutes, during which pupils are passive and take in the information given by the teacher, writing down what they have learned in their notebooks (notebooks, tablets). During this time, pupils should not ask questions so as not to disrupt the teacher's coherent speech and the concentration of their classmates, but are encouraged to take notes and ask questions after the lesson (either what they need to be explained again or to respond with specific questions to expand on the explanation).

The first phase must be well prepared, whether in the form of an engaging narrative, presentation, documentary, demonstration experiment or text. During this phase, the necessary information is provided to understand and further study the topic. Didactic analysis is important – i.e. to select what is really important for following activities and understanding of the context, and to discard the part of the material that is learned by "inertia through habit". On the other hand, the lesson must not be lengthy for the pupils, the attention span curve must be worked with, and at the same time there must be enough time for pupils' activities in the second phase. Only after this phase does the individualisation of teaching come in.

Phase 2: Individual and group work of pupils

The aim of the second phase of the block is to work with extension information to the lesson, to verify the theoretical knowledge or to practice and learn the topic. In this phase, pupils are active, work individually in worksheets (uniform for all pupils) or in groups (usually of four pupils) to solve a given problem (in the classroom, in the laboratory, in the school premises or, on appropriate occasions, in the field).

Pupils write down their results and check them using a key in the case of worksheets, or record their findings in a laboratory report. They have the opportunity to consult the teacher. At the same time, the teacher focuses on formative assessment of pupils (e.g. using effective questions, feedback, rubrics or portfolios) to help pupils achieve better results and, most importantly, each pupil is given individual reasons why and how he/she can improve. The teacher is here in the position of a consultant. Once again, a high quality preparation of all the materials (worksheets, keys, instructions for laboratory work, optional work, etc.) is essential. At this stage, the pupils can create tools, e.g. by laminating cards (element symbols), by doing small jobs with a melting gun (especially in physics), by creating didactic games to practise the material (board and online).

The main advantage of this arrangement is the individual pace of the pupils, the possibility of optional activities, cooperation in group work, and the development of learning competence (especially through targeted planning of the learning process and its evaluation). In group work, there are usually two secondary and two tertiary pupils present. During peer learning it is necessary to take care of the basics of psychohygiene,

i.e. not to overload pupils with frequent "teaching" of younger classmates and older pupils do not take over the role of teacher as we know it from classical teaching. The disadvantages can be low self-discipline, inappropriate time management by the pupil, short-term knowledge of the discussed block, disorganisation of the own portfolio. Therefore, in phase 3, self-assessment follows, so that the pupil himself reflects on what he could have done better to achieve better results next time and be more satisfied with his performance.

Phase 3: Sharing the findings/outcomes and reflection on the work

The last phase involves sharing the results of the pupils' work (either in larger groups or centrally for the whole class). During this phase, pupils present their results to other classmates, defending their views supported by their findings from working with sources or from measurements. They receive feedback from classmates and the teacher. This is followed by a summary of the unit,

Natural Sciences: Chemistry

Group Work Assignment

Objective: Create a group presentation on the topic of chemical reactions.

Timeline: _____ Group allocation

_____ Brainstorming ideas for the group project and reporting to the teacher

_____ Creating a mind map

_____ Researching information and taking notes

_____ Preparing the presentation

_____ Project presentations (date: .....)

In my group are:

Our topic:

What will our presentation look like? (number of slides, graphics, etc.)

How will we plan our work and who will have which role?

The presentation must include the title, full names of the group members, researched information, images, questions for classmates at the end, and correctly cited sources. The minimum presentation length is 5 minutes. Do you want to add anything else?

Fig. 3. **Group Work Assignment** (skip blank lines, standard A4 format)

e.g. each pupil says or writes down what they have remembered/learned new things and can add what they found challenging and what they did well.

Large group work at the end of the topic

After completing all the lessons and the required tasks, students work on a large group

work (shown in Fig. 3). Together they discuss the topic, they can create mind maps, practise hypothesis setting, testing them from different sources and carrying out experimental work, argumentation, understanding in context and, at the end of the group work, presentation skills. In the timetable, students schedule their work (e.g., what they will do during particular class period). The teacher is in the position of evaluator and moderator, inviting others to give feedback or to guide the discussion.

After the final outputs, students are given the opportunity to self-assessment, usually in writing, each completing the evaluation on his/her own, and then the group members come together and compare the pie chart (Fig. 4), discussing the results and the reasons why they divided the share of work among their classmates in a given way, while also evaluating their own individual work (Fig. 5). For example, pupil rates himself/herself at 90%, writes down what he/she did well (praises) and what he/she lowered his/her percentages for (where he/she see area for improvement). Peer review and self-assessment during the final exams takes approximately 10 minutes. At the beginning, pupils should be guided into the skill of peer assessment and self-assessment, for example by providing incomplete sentences for pupils to complete. Examples of such sentences could be "*Excellent idea was..., If I were in your place..., I appreciate that...*" For this way of working, regular training and self-education of teachers in professional, didactic and Montessori pedagogy is necessary. The emphasis is on both theory and practice. Even in Montessori training, it is necessary to try out the components for oneself and to discuss their aims and use with trainers and colleagues. Everything may not turn out well the first time it is implemented with students, so it is important to keep notes on how to approach the activity differently next time. It is also helpful to visit colleagues' classes and provide feedback from peer observations.

6. Conclusion

The article presents the teaching of chemistry at the lower level of the Montessori Gymnázium Duhovka and outlines the contribution of individual activities and procedures for the development of knowledge and key competences of pupils. Among the elements presented were the importance of choice (both in the selection of topics and activities for practicing the curriculum), the merit of working with a heterogeneous group of pupils (which teachers may know for example from optional courses), the curriculum introduced in advance, aims, and standards of assessment (StudyGuide), logical interconnection of the three-phase teaching, possibilities of formative assessment during group and individual work or assigning progressively more challenging tasks (larger group work, inquiry day, output after two years of teaching), so-called graduated teaching. Very important is also the principle that even in integrated science teaching, integration need not be complete, but only parts of the subjects can be connected according to appropriate topics and the school's capacity in terms of staffing and space.

In case of implementation of selected elements from the article in a classical school, we recommend to focus on one element initially and try to apply it in practice or adapt it to your needs and the needs of your students. It is recommended to add more elements later, because both the teacher and the students have to get used to the new teaching elements and changes in teaching. Finally, it is important that the inclusion of the selected activities makes sense to the teachers, that their benefits are clear to the pupils and that they fit in with the educational concept

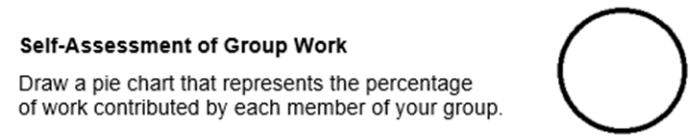

Fig. 4. **Evaluation of the contribution to group work**

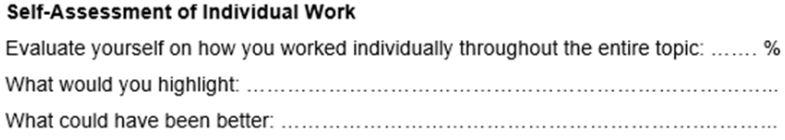

Fig. 5. **Example of self-assessment during individual work at the end of the topic**

of the school. The changes may be challenging, but the reward will be happier and more enthusiastic pupils.

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