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Engaging students for meaningful chemistry learning through Microcomputer-based Laboratory (MBL) inquiry

Promoure en els estudiants l'aprenentatge significatiu de la química mitjançat treballs pràctics indagatius amb l'ús d'equips de captació de dades amb sensors (MBL)

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abstract

The Microcomputer-based Laboratory (MBL) is an example of a student-centred learning environment that provides new opportunities to engage secondary-level chemistry students in meaningful learning and higher-order thinking through inquiry. MBL promotes student discussion, planning, measuring and taking responsibility for their own study processes. MBLs support an environmentally benign (green chemistry) approach in the school by reducing the amounts of chemicals needed. This article presents a pedagogical research-based view of its effectiveness, the challenges faced when using and some tips for implementing it in chemistry classrooms at high school level.

keywords

Microcomputer-based Laboratory (MBL), data-logging, chemistry, high school.

resum

La utilització d'equips de captació de dades amb sensors (MBL) pot constituir un exemple d'entorn d'aprenentatge centrat en l'alumne que ofereix noves oportunitats per acostar els estudiants de química de l'ensenyament secundari cap a un aprenentatge significatiu i cap al pensament d'ordre superior a través de la indagació. L'ús de MBL promou en els alumnes la discussió, la planificació, la mesura i la presa de responsabilitat del seus propis processos d'aprenentatge. La tècnica MBL pot contribuir des de l'escola a propostes respectuoses amb el medi ambient (química verda) mitjançant la reducció de les quantitats de productes químics necessaris. Aquest article presenta una investigació pedagògica de l'eficàcia d'aquesta tècnica, dels seus reptes d'utilització i alguns consells per implementar el seu ús a les classes de química de secundària.

paraules clau

Equips de registrament de dades amb sensors (MBL), registre de dades, química, ensenyament secundari.

Introduction

The Microcomputer-based Laboratory (*MBL, called a data-logging package in the U. K.)* has been used in chemistry education since the 1980s. Tinker and his colleagues at Technical Education Research Center make the MBL possible (Tinker & Stringer, 1978).

MBLs are tools that use microcomputers for data acquisition, display, and analysis (fig. 1). Similar to activities of chemists, students can use probes and associated software to direct the computer to collect, record, and graph, for example temperature, voltage, pH, or dissolved oxygen data (e. g. Novak & Krajick, 2004) (fig. 2).

The MBL allows students to complete laboratory activities

Figure 1. An example of Microcomputer-based Laboratory (MBL) tools.

Figure 2. Students using a colorimeter of the MBL equipment.

that were previously impossible or impractical to implement (e. g. Nakhleh *et al.*, 2002). MBLs also allow possibilities to study chemical phenomena outside of schools, i. e. make field experiments, for example in nature (e. g. Lavonen *et al.*, 2003; Tinker & Krajick, 2001).

MBLs offer new possibilities to integrate experiments in the chemistry classroom. In particular, it allows investigative styles of working: experiments can be readily repeated, generating more data for analysis; or students can manipulate the parameters of experiments, and replicate them (e. g. Newton, 1997). Students can repeat their measurements easily, even using the same screen image, offering possibilities of comparing gathered results easily (Lavonen *et al.*, 2003) Students can compare, for example, two exothermic reactions (Aksela & Heikinaho, 2004) (fig. 3).

MBLs extend experimental possibilities beyond standard laboratory apparatus (e. g. Tortosa, 2008). They assist in managing the collection, display, storage, modeling, and analysis of laboratory data. The MBLs provides opportunities to study the ideas of chemical reactions, even in the context of organic chemistry. In particular, most organic reactions cannot be readily conducted safely with the available facilities for secondary-school laboratory work.

MBLs also support an environmentally benign (green chemistry) approach in the school laboratory just as it had done in modern research laboratories. It can reduce the amounts of chemicals needed and providing opportunities to study chemical phenomena (e. g. heat of reaction, pH), even in microscale (Aksela, 2005). This is not easily accomplished with traditional methods in schools.

Conducting experiments in microscale can offer many advantages over conventional methods such as waste reduction, low cost, ease of use, enhanced safety, and shortened work time. The six-well template system can serve as a simple calorimeter. It's a plastic microscale template for MBL studies with two holes in the lid (fig. 4). One hole is for a temperature probe and the other is to add reactants with a pipet. A magnetic stirrer can be used for stirring the reactants. This system provides an opportunity for students to study six reactions quickly and safely in a green chemistry approach (Aksela, 2005).

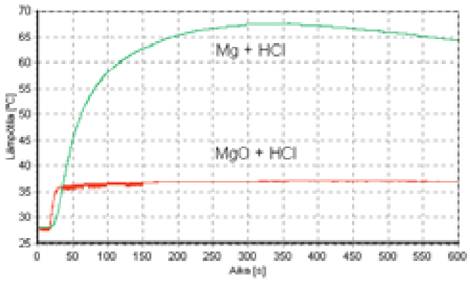

Figure 3. Graph comparing the temperature evolution with time in two exothermic reactions.

Figure 4. Green chemistry approach. A plastic microscale template used as a calorimeter.

The effectiveness of MBL for chemistry instruction

Few studies have focused on MBL environments, on how students construct knowledge (i. e. using their higher-order thinking in chemistry) using MBL, or how MBL, in turn, affects students' perceptions and interpretations of chemical phenomena, or how MBL can support students' meaningful learning in conjunction with pedagogical models (strategies) (e. g. Lavonen *et al.*, 2003; Nakhleh, 1994).

There can be found many advantages of the use of MBLs in science instruction from research literature. They offer students new possibilities to see data presented in ways that increase the understanding of chemistry (Aksela, 2005). The MBL is effective at communicating scientific data, because MBL (*a*) represents data in multiple ways, (*b*) graphs in real time, thereby displaying the physical event with the symbolic graph, (*c*) allows students to investigate phenomena in a manner similar to scientists, and (*d*) allows students to concentrate on the interpretation of the graph rather than the production of the graph (Mokros & Tinker, 1987).

In addition, MBLs develop skills of investigation, reflection, and analysis, generate and refine conceptual change, find solutions to problems, and pose questions for further inquiry (McRobbie & Thomas, 2000). Students can become more confident in their own abilities to design experiments, articulate hypotheses, control variables, interpret data, and make conclusions based on the data and the hypotheses (Zuman & Kim, 1989). MBLs also provide opportunities for more autonomous, independent, and exciting scientific investigations and, thus, engage students in learning chemistry (Linn, 1995; Nakhleh, 1994). According to Lapp & Cyrus (2000), it can also give students a sense of confidence in their work.

The MBLs motivate students to study chemistry. Students display considerable interest in conducting experiments and using MBLs (Adams & Shrum, 1990; Aksela, 2005; Amend & Furstenau, 1992; Atar, 2002; Newton, 1997). The real time connection between the event and developing the graph is particularly motivating for students and promotes their attitudes towards chemistry (Nachmias, 1989), even for those who encounter problems in drawing graphs on their own.

MBLs can support meaningful chemistry learning and higher-order thinking (Aksela, 2005). They can assist in students' knowledge construction (Nakhleh, Polles & Malina, 2002), and help develop concepts and skills (Igelsrud & Leonard, 1988; Nakhleh & Krajcik, 1994; Tinker, 1996). According to Friedler, Nachmias & Linn (1990), the MBL is an appropriate environment, in which to teach scientific reasoning skills, such as prediction and observation. In particular, the value of the MBL learning environment to practical work lies in analyzing and interpreting data (Roger, 1997). According to Nakhleh & Krajick (1994), students increased their levels of understanding of acids, bases, and pH compared to students who used more traditional laboratory approaches (using pH meters and indicators).

MBLs free students to devote more attention to observation, reflection, and discussion (Rogers, 1996). Students need less time to understand relationships between theory and practise compared to traditional laboratory approaches (Friedler, Nachimias & Linn, 1990).

MBLs conserve lesson time because of the relative ease with which experimental data are captured and presented (Rogers & Wild, 1996). Students in a conventional laboratory setting require twice as much time as those in the microcomputer-based laboratory (e. g. Schecker, 1998). Thus, the MBL environment also allows students more time to discuss, plan, and take responsibility for their study processes (e. g. Domin, 1999).

The benefits of MBLs in promoting meaningful learning are facilitating immediate observations of data, seeking answers to questions of about the data, looking for links with other information, making comparisons, predicting, and looking for trends —i. e., the benefits of MBL arise from stimulating the quality of students' thinking about the data (Roger, 1997). The immediacy of graph production is one of the most important features of MBL activities (fig. 5).

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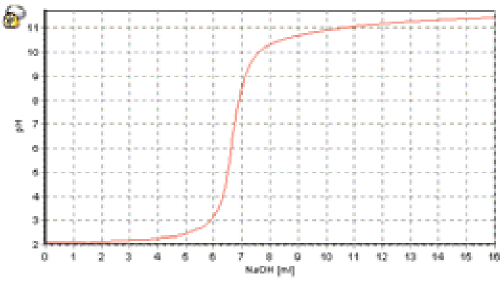

Figure 5. A student performing a pH curve registration and the corresponding graphic.

With MBLs, a graph of gathered quantitative data becomes a starting point for student thinking (Newton, 1997). A graph enables the student to construct a bridge between thephenomenon and its formal presentation. It provides opportunities for viewing a complete process rather than discrete phases of the process, as in an ordinary laboratory setting. Thus, students are free to think and solve problems without being overloaded with technicalities (Nachmias, 1989). Graphs extend memory and facilitate information processing (Tversky, 2000). They are like cognitive tools. Real-time MBL affects student learning placing less of burden on students' short-term and long-term memory for processing and maintaining information (Brasell, 1987).

The challenges of MBL for chemistry instruction

Without appropriate conceptual understanding in chemistry, students may fail to observe the phenomenon under investigation or, on occasions, may observe something else entirely (Atar, 2002; Friedler, Nachimias & Linn, 1990). However, it has been found that MBLs do not necessarily promote learning for all students, especially slow-paced students requires often special attention (Atar, 2002).

More practice is, however, needed for students to think about data represented by graphs to identify properties and relationships in chemistry, and also for students to gain practice in talking about graphs (Newton, 1997). Students need time to practice describing and using patterns to engage in necessary reflection upon their results and discussions with their teachers (Rogers, 1995). There is a difference between interpreting the findings of real-time data collection and completing graphs by hand. Students are better at interpreting the MBL-generated graphs (Mokros & Tinker, 1987). Learning from graphs requires skills, such as comparing data, using cursors, performing calculations, fitting curves, and altering scales.

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The interpretation of graphs depends on the ability to understand global features such as intervals, maxima and minima, and discontinuities (Roger, 1996). According to Atar (2002), students respond differently to the immediacy of data. Some students said that it reinforced their learning and promoted their engagement with the experiment, while others believed it confused them, preventing them from understand, what was really going on in the experiment. There were some things students did not understand about graphing: the sensitivity of the graphing scale, and the way that the MBL displayed data. Effective incorporation of MBLs into laboratories to analyze scientific data is much more related to the graphing skills of students than to their school grade level (Atar, 2002; Rogers, 1995).

Features of graphs are the language of graphs through which meanings about them are conveyed (Dreyfus & Mazouz, 1992). Observations of students using MBLs indicate that their talk can lead them to a better appreciation of the meaning of their data and their skills in communicating it (Newton, 1997). MBL promotes student-student interactions and peer group discussions (Nakhleh, 1994). Much of students' talk about their graphs is, however, descriptive in nature, and much of their vocabulary is unscientific (Aksela, 2005; Newton, 1997). Some students may describe patterns in graphs using everyday language without appreciating the underlying meaning or significance of the graphs themselves. A large proportion of novice ICT-user talk might be termed «operational talk» concerned with students' setting up and managing equipment (Aksela, 2005; Newton, 1997). The students' choice of words seems to refer to the «behavior» of a graph as a dynamic, changing form, something like a «movie» of the data (Aksela, 2005; Newton, 1997).

The instructional effectiveness of MBL is linked to the pedagogical approach employed (e. g. Aksela, 2005; Krajcik, 1991; Linn, 1995; Nakhleh, 1994; Nakhleh, Polles & Malina, 2002). Students' activities must be carefully structured. Some student groups spend time apparently doing little more than looking at the MBL hardware log data and presenting a graph (Newton, 1997). An MBL activity cannot in itself teach anything or enhance student learning in chemistry; the MBL must be embedded within a curriculum, a school, and a social context (Newton, 1997; Tinker, 1996). Instruments can either encourage or hinder cognition about scientific concepts (Malina & Nakhleh, 2001). In particular, some students did not find it easy to provide verbal descriptions of graphs (Barton, 1997). Thus, the design of a classroom activity is central (Aksela, 2005; Rogers, 1997).

The starting point for planning must be to identify the purpose of the task in terms of anticipated learning outcomes. Student also need to invest time to gain familiarity and confidence in using these software tools, but experience shows that the time needed to bring students to an efficient threshold of skill can be quite modest (Rogers & Wild, 1994). Students' interactions with the teacher are important in maximizing potential benefits from MBL use (Aksela, 2005; Barton, 1997; Lavonen *et al.*, 2003; Newton, 1997). Whenever possible, teachers should engage students in discussions on the meaning of graphical data (Barton, 1997).

Talking to students about their graphs improves their ability to describe them and encourages them to reflect on their meaning. Using just a few prompting questions that encourage students to think more deeply about what they have said, can significantly affect their interpretations of the data (Barton, 1997). Questions related to investigating a chemical reaction can be, for example, questions showed in table 1 (Rogers, 1997).

Table 1. Questions to help students in the interpretation of the data in an MBL investigation about chemistry reaction

- How long does it take for the reaction to start after the solutions are mixed?
- Does the reaction proceed at a steady rate?
- How do you know when the reaction has finished?
- How long does it take for the reaction to finish?
- If you dilute the solution, how does this affect the reaction time?

In addition, students need also careful task analysis and class discussion to counteract the formulation of inappropriate concepts (Nakhleh & Krajcik, 1994).

The learning outcomes appropriate to a task clearly depend on the context, but these are some general objectives (Rogers, 1997): (*a*) a student is able to use a graph to describe events in an investigation; (*b*) a student is able to make connections between observations and graph shape, (*c*) a student has knowledge of variables which affect each other; (*d*) a student describe patterns and relationship between variables; (*e*) students are aware of the properties of linear relationships, (*f*) students interpret data in terms of previously learned theories; (*g*) students understand how theories can be tested by examining data; and (*h*) students make predictions from collected data.

Nahkleh *et al.* (2002) emphasize the aspects included in table 2 to support meaningful learning through laboratory activities (e. g. MBL).

There is, however, a need for additional research in naturalistic settings within chemistry classes, especially focusing on how students construct knowledge in chemistry using MBL, and how MBL, in turn, affects students' perceptions and interpretation of physical phenomena, or how to support student learning using MBL with various teaching strategies (Aksela, 2005; Lavonen *et al.*, 2003; Nakhleh, 1994).

Table 2. Advice and guidance to support meaningful learning through laboratory activities as MBL

- Experiment should have practical, real-world connections.
- Pre- and post-laboratory oral discussions.
- Limited, specific goals of laboratory activities.
- Design labs so that procedural skills or instruments that student use are clustered in several labs.
- Encourage students to ask «What if?» questions to help them explore the boundaries of the topic.

Nakhleh (1994) reviewed three major areas of MBL research in science education: (*a*) students' understanding of graphing using MBL, (*b*) students' development of science concepts using MBL, and (*c*) students' understanding of scientific experimentation using MBL. For example, Nakhleh & Krajcik (1993) had studied secondary students' thoughts during acid-base titrations using either MBL, a pH meter, or an acid-base indicator.

One possible use of the MBLs is to connect practical investigations with computer-based molecular modeling (Aksela & Lundell, 2008). For example, students can first model chemical phenomena studied like chemists through molecular modeling program, second make experiment(s) in laboratory and finally explain the phenomena by using computer-based modeling.

An example of MBL pedagogical use in chemistry instruction

The effectiveness of MBL tools depends much on teachers' understanding of how to use them (e. g. Lavonen *et al.*, 2003). In this example, students' higher-order thinking in chemistry is supported through a cooperative learning and learning cycle approach (Aksela, 2005). In particular, the learning diary and concept mapping is assumed to work as metacognitive devices (e. g. White & Frederiksen, 2000) to promote social discourse and, thus, student thinking. Peer interaction can particularly provide necessary positive and supportive environments for higher-order thinking, encouraging students' thought and discourse in chemistry. The teacher's role is seen as a coach who stimulates students' initial thinking skills and guides them towards the learning goals.

According to Lawson *et al.* (1986) and Aksela (2005), the learning cycle is suitable teaching method, in particular, when the development of thinking skills is a main goal. A five-stage learning cycle including *Exploration*, *Explanation*, *Elaboration*, *Evaluation*, and *Reporting* (EEEER) can be implemented to support meaningful chemistry learning within student-centered MBL inquiry. It can include aspects considered in table 3.

A jigsaw model of cooperative learning (Aronson *et al.*, 1978) can be incorporated in the computer-assisted MBL inquiry (Aksela, 2005). During the cooperative inquiry, every student can share their thoughts and what they had learned with each other, and reflect on their learning. Working in small groups, students can complete investigations in their home groups during their first inquiry session, and later, within expert groups. There can be three or four home groups with three to four students in each group in studies. Each group can have its own color (red, blue, green, or white) to easily distinguish the groups. During the second session, students can teach what they had learned from the first session to other students in their expert group. Then, students can teach to their home group to reflect on their learning and complete concept maps and a learning diary. Different roles, selected by students (such as leader, secretary, computer assistant, and assistant working with chemicals) can be useful in the studies.

Table 3. A five-stage learning cycle including EEEER implemented with student-centered MBL inquiry

- Conducting MBL-based investigations (the *Exploration* Phase).
- Drawing a concept map of the chemical reactions (the *Explanation* Phase).
- Conducting a teaching session, where students teach what they have learned to the other team members (the *Elaboration* Phase).
- Writing a learning diary that provoked students to reflect on their learning during their inquiry within small co-operative teams (the *Evaluation* Phase).
- Writing a report of their results (the *Reporting* Phase).

Examples of MBL activities in chemistry

There can be found many MBL school activities from Internet in chemistry (e. g. Aksela & Heikinaho, 2004; Vernier, 2011; Pasco, 2011). It can be studied, for example the following chemical phenomena: (I) endothermic and exothermic reactions, (II) effect of temperature on solubility of a salt, (III) properties of solutions and non-electrolytes, (IV) energy contents of fuels, (V) heat of combustion: magnesium, (VI) acid-base titration, (VII) determining the quantity of Iron in a vitamin tablet, (VIII) acid rain simulation or (IX) ideal gas law.

The MBL investigations can serve as a novel strategy to support students' learning of ideas of organic reactions (Aksela, 2005). Open inquiry can be studied by given open task instructions, tools, and materials to students. For example, table 4 shows three student investigation tasks within the MBL tool that can be studied.

Table 4. Student investigation tasks within the MBL tool

- Task 1. A study of four chemical reactions (exothermic and endothermic reactions, two acid-base and two esterification reactions), by using a MBL temperature probe.
- Task 2. A study of aspirin synthesis (to determine which factors affect the reaction rate), by using a MBL temperature probe.
- Task 3. A study of the reaction of an organic acid, acetic acid and NaOH (titration).

The open-ended task instructions can be stated as follows, for example: «Study the properties of four chemical reactions using the MBL tool». In particular, the emphasis is on engaging students in higher-order thinking regarding the ideas of chemical reactions through tasks that can «anchor» students' to meaningful learning.

The tasks were re-designed to resemble more real world situations to motivate students to transfer their knowledge and skills. The tasks, with little stories, resemble plays with «chemist» roles where students help a chemist solve problems.

Task 1 consists of the following story (freely translated to English): «A chemist needs to solve the following real problem in a research center. Does a chemical reaction happen between the following substances (acetic acid + natrium hydroxide, formic acid + natrium hydroxide, acetic acid + n-butanol, formic acid + n-butanol)? A chemist asks your help. How can you infer it? What happens in each reaction? Compare the reactions and classify them according to their properties. Describe your results in every stage of your inquiry. At the end of your study, please, send the chemist your answers to the questions concerning your research». Students are assumed to compare, classify and analyze different graphs of data on the same computer screen to make sense of the phenomena (creating/synthezising). Thus, students can confront and resolve real cognitive conflicts. In addition to this, it is also assumed that students start to use their higher-order thinking to understand the difference between the reactions (e. g. heat of reactions, rate of reactions, exothermic and endothermic reactions, acid-base reactions, esterification) and how and why the reactions happened. They can also think them in symbolic level. Students can also generate many questions of their own to investigate.

Students' comments on the MBL activities used (Aksela, 2005): *«It was good to see reactions in practice without being told about»* (a view expressed by one senior-level student after the inquiry). In addition, it can inspire students' chemistry learning: *«If only chemistry classes could always be like this!»* (a view expressed by one junior-level student after the inquiry).

Conclusions

Student-centered MBL learning environments are needed that encourage and inspire secondary-level students to strengthen and establish a broad range of conceptual, procedural, and meta-cognitive knowledge, and also a broader range of cognitive processes (i. e. HOTS) at school. The teacher's role is important: she/he is like a catalyst who stimulates students' with right questions and tips.

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