WP2: Adapting existing research based materials on real time experiments to a common competencial framework in COMBLAB (**UW**,UAB,CU,UB,UH,UMB)

DELIVERABLE 7

Key points in research based worksheets for students to achieve scientific competencies through real time experiments

Contents

A review of research findings on real time experiments suggests looking at this issue from three perspectives: First of all, the challenge is to identify the potential benefits of using computer-aided practical work. Secondly, students have to be properly guided when they use technology in the classroom. Finally, support for teachers has to be provided aiming at the development of their TPCK (Technological Pedagogical Content Knowledge) and helping them to make innovative changes in the use of computer-aided practical work to support concept development in biology, chemistry and physics education.

1. Addressing the gulf between potential benefits and difficulties of realizing them

A pilot study aimed to explore ways in which teachers could be supported to enhance the development of pupils' understanding of physics concepts (Barton, 2005). The study was based on a *collaborative partnership between a researcher and a classroom teacher.* The indications are that there is the potential for considerable benefits from such an approach, with the need for further development of materials and teaching methods being identified. The software tools and teaching approaches used made possible to perform measurements which wouldn't be possible using traditional approach. Using worksheets which asked students to compare different kind of resistors provided good feedback on their level of understanding, as did their responses to the question relating to the characteristic for the bulb. Asking students to first predict and then measure the graphs was thought to be a good exercise, although challenging. The final modeling activity could also be used as a model for more challenging activities. The different kind of graphs and their simultaneous use provide a good focus for student-teacher discussions. Analyzing this discussion is seen essential for evaluating the potential of computer-aided practical work. Findings of this pilot study suggest that computer-aided practical work should be set into a context which involves both routine use of data logging and centrally the use of software tools. Additionally, the activities designed should also include a plan for teacher-learner interactions.

2. Educational implementation and active engagement are important

Investigations show that MBL-labs are an effective tool for the development of a good conceptual understanding in mechanics (Hamne & Bernhard, 2001; Thornton & Sokoloff, 1990). Microcomputer Based Labs (MBL) have successfully been implemented in physics courses for pre-service teachers. In MBL-labs students do real experiments and not simulated ones and the computer is used as a measurement tool together with an interface and suitable sensors. Conceptual change/concept substitution is facilitated by taking advantage of the real-time display of the experimental results by the computer and by labs emphasizing concepts and connections between concepts. The MBL tools allow students to take an active role in their learning and encourage them to construct physical knowledge from observation of the physical world. Furthermore, the MBL tools enhance collaborative learning by taking advantage of the fact that data are presented in an immediately understandable graphical form. There is strong evidence for significantly improved learning and retention by students who used the MBL materials, compared to those taught in lecture. Evaluating the learning results with the FCI- and the FMCE-test shows good learning results. However, the data also show that the educational implementation of MBL is crucial. To take full advantage of MBL the educational implementation is important, not the technology. Active engagement is important.

3. Substantial learning gains possibly higher than with traditional methods

The Technology Enhanced Elementary and Middle School Science II project (TEEMSS), funded by the National Science Foundation, produced 15 inquiry-based instructional science units for teaching in grades 3–8 (Zucker et al., 2008). Each unit uses computers and probe ware to support students' investigations of real-world phenomena using probes (e.g., for temperature or pressure) or, in one case, virtual environments based on mathematical models. TEEMSS units were used in more than 100 classrooms by over 60 teachers and thousands of students. In four cases (sound and electricity, both for grades 3–4; temperature, grades 5–6; and motion, grades 7–8) there were significant differences in science learning favoring the students who used the TEEMSS materials. The effect sizes are 0.58, 0.94, 1.54, and 0.49, respectively. For the other four units there were no significant differences in science learning between TEEMSS and non-TEEMSS students. Teacher and student attitudes towards TEEMSS units were positive and they valued the use of sensors and being able to see the graphs produced immediately.

Students' knowledge increased during the units in both the traditional and MBL teaching.

In four out of eight units that were researched the MBL based teaching was statistically significantly more effective than traditional teaching. These units were sound, electricity (3rd-4th grades), temperature (5th-6th grades), and motion (7th-8th grades). There were no differences neither in the time used for these four units compared to other four nor the students' level of engagement. A possible explanation could be that MBL is more effective for teaching some concepts than other, and that the teaching of concepts which can be learned more easily with the use of graphs take more advantage of the use of MBL. Using MBL in elementary and middle schools can result in substantial learning gains and in some cases this gain can be higher than with traditional learning methods.

4. From data collection to data interpretation

Much laboratory work in school science involves observation and measurement. In fact, important development, in recent years, has been the application of computers to this activity. Data-logging techniques have been available to science teachers for some time. It is only relatively recently, however, that data-logging technology has become sufficiently user-friendly and affordable for it to be more widely adopted. The use of sensors, interfaces and data-loggers to capture and record data, and its subsequent display and analysis using computer software, now constitute a realistic alternative to traditional approaches. Crucial is to encourage learners to engage in more interpretative activity, which recent software readily supports. A shift of emphasis from data collection to data interpretation and increased awareness of pupils' roles offer the prospect of more effectively exploiting data-logging activities to enrich pupils' experience of science and of meeting the demands of an increasingly technological curriculum (Newton, 1998).

Therefore, a good MBL activity should take following matters into account:

- Encouraging interaction between students. This could be achieved by working in groups and encouraging students to talk about what they are doing and finding out.
- Giving students responsibility. This could be achieved by giving each student a different role in one's group.
- Students knowing their role. The technical aspects of MBL shouldn't overshadow the students' need to know the objectives of their actions. They need to have previous skills of identifying variables and deciding what measurements to make

before they can manage these things in MBL activities.

- Students' attention can be focused too much on data collecting, neglecting the analysis of collected data. They need support in separating the important and unimportant observations. This could be helped by asking them to make predictions of what will happen.
- After learning to manipulate the MBL equipment, students should learn to understand and evaluate the collected data. This could be achieved in the context on investigation activities.

- Learning to deal with anomalies in the collected data. Students need the skills to explain why the data they have collected in MBL activity may have anomalies.

5. Computers affect graphical interpretation

Findings of a comparative study involving data-logging, conventional practical work, and a no practical equivalent suggest that the computer-based approach seems to be particularly effective for younger and less-abled pupils (Barton, 1997). Three ability groups of year 8 and year 10 students were formed. Each ability group consisted of three pairs. Pairs studied relationship between current and voltage in different components. In each group of three pairs, one pair used MBL equipment, one traditional practical work and one ready sets of measurement data. MBL groups used data-logging to produce the graphs of current against voltage for different components, while the groups using traditional practical work executed the measurements and produced the graphs manually. Those groups with ready-given data only draw the graphs. The structure of activity was similar to all three sets of groups.

- The computer approach appears to be superior to the non-practical approach since it is more flexible and offers real-time plotting. It allows more investigations to be conducted and gives pupils the option of extending the investigation by collecting new data.
- Manual graph plotting should be avoided when the main aim is to interpret relationships via graphical analysis, particularly with younger and less-able pupils. It causes serious time penalty and results in pupils focusing on individual data items rather than the continuous relationship between the variables.
- Sketch graph predictions followed by plotting data for confirmation, has proved to

be effective in promoting discussion. Due to the small time lapse between prediction and the final graph being plotted, the computer approach is particularly appropriate.

- Wherever possible teachers should engage pupils in discussions on the meaning of graphical data. Teacers should encourage pupils to discuss their ideas.
- The combination of real-time display of data and prompt questions from the teacher was a potent combination in assisting with the interpretation of graphical information.

A good analysis and interpretation of plotted graphs is important for students. It is also important the way students are helped to comprehend the experimental relations. Some investigations (Sorgo & Kocijancic, 2011) showed that the teacher's ability in this field is crucial as well. The research showed that especially in Biology some hidden obstacles can discomfort the interpretation of graphs obtained by data-loggers. It was referred that some of the Biology teachers not trained in Physics, Chemistry, Mathematics, and Computer Science have difficulty finding explanation at the moment when it is needed.
In a research Sorgo and Kocijancic (2011), monitored the Biology teachers on how they face with the problems that could arise during performing the MBL experiment in Biology. The authors' findings concerning the understanding of graphs are the result of more than 50 different laboratory exercises tested in the classroom and of in- and after-class discussion with science teachers attending in- service training or via e-mail communications. In this research, four areas of the difficulties with graphs (in Biology) have been pointed out:

- Explanation of the curves is beyond the domain of Biology, but lies in Physics, Chemistry or some other discipline. The fundaments of some biological processes cannot be explained properly only in a “biological” way. Technology cannot find answers on some biological processes (presented by graphs) in their domains but only in that of Physical Chemistry.
- Hardware properties. The biology teachers are not very well experienced in using computers in laboratory education. In practice this means almost every teacher who has been in the classroom for more than 20 years. Even younger teachers rarely have the appropriate knowledge. They know how to use the computer as a typewriter, a storage device, presentation tool, and for access to the Internet, but

they rarely possess this kind of knowledge.

- Unknown properties of experimental components;
- Occasional equipment breakdowns or crashes.

According to the results authors claim and suggest that:

- the ideal Biology teacher should be trained in Physics, Chemistry, Earth Sciences, Environmental Sciences, Mathematics, and Computer Sciences,
- For a good interpretation of graphs obtained from biological systems, a teacher needs proficiency in understanding not only Biology but other disciplines as well. When working with computers and equipment for measurements, he will face problems such as analog-digital processing, nonlinearity, noise, sampling, log-linear transformations, etc.
- Teachers need considerable training before they are able to introduce new methods into the classroom.

6. Helping students by asking open questions about graphs

Real-time graphing encourages qualitative description of the graphs. Observing aspects of students' talk about real-time graphs, suggests that such talk may help to develop students' appreciation of the meaning in their data and their skills in communicating about it (Newton, 1997). This can help teachers plan approaches to data-logging activities that exploit these benefits. However, students use language that is metaphorical and is based on their normal vocabulary. Students need help in understanding the graphs. Teacher can use questions to encourage students in analyzing the graphs features. Teacher's assistance is needed to evolve students' language to more scientific direction. This can be done by discussing about the graphs with the students and sharing more acceptable descriptions of the data collected. Students need the help of the teacher to be able to understand the graphs produced and their significant features. Teacher can help them by asking open questions about the graphs. MBL activities need to be designed so that students are active in all phases of the activity, including the data-collection.

7. New data-logging tools afford new investigations

The gathering of data using data-loggers is only the beginning of the process of learning from computer-aided practical work (Rogers, 1997). There is much investigating to be done on the collected data by exploiting the tools now commonly featured in data-logging software. Attention has to be drawn to the importance of designing tasks that encourage pupils to think about the data and the principles which underpin worthwhile data-logging tasks are suggested. Viewing the data collected with MBL equipment only as the beginning of an activity, ideal MBL activities should encourage students to develop a habit of asking questions about the data and making links with their science knowledge. Students should be able to use different strategies and MBL tools to analyze the graph produced in measurements and to reach the learning outcomes of the activity. Learning outcomes could be for example being able to use a graph to describe events during the measurement, or describe patterns and relationships between variables. Possible strategies student can use in analyzing the data are for example: looking for trends or details, comparing different graphs, or looking for similarities and differences. The MBL tools could be for example the used software tools which give different statistics of the produced graphs (gradient, minima, maxima…). Given examples should illustrate how graphs produced in MBL activity can encourage students to think about the data and explore it in different ways.

8. Immediate student control might make MBL effective

Real-time MBL experiments allow students to “see” and, at least in kinematics exercises, “feel” the connection between a physical event and its graphical representation (Beichner, 1990). In Brasell’s examination of the sonic ranger MBL, a delay of graphing by only 20 seconds diminished the impact of the MBL exercises. The article from Beichner (1990) describes a study where kinesthetic feedback was completely removed by only giving students’ visual replications of a motion situation. Graph production was synchronized with motion reanimation so that students still saw a moving object and its kinematics graph simultaneously. Results indicate that this technique did not have a substantial educational advantage over traditional instruction.
Since Brasell and others have demonstrated the superiority of microcomputer-based labs, this may indicate that visual juxtaposition is not the relevant variable producing the

educational impact of real-time MBL. Immediate student control of the physical event and its graphical representation might be what makes MBL effective and, in the case of kinematics laboratories, kinaesthetic feedback could be the most important component of the MBL learning experience. The kinesthetic sense is a strong one and appears to make a difference in kinematics MBL's. Perhaps other areas of student investigation would not have as great a requirement for real-time data collection and display.

9. Communicating with graphs in the context of appropriate MBL investigations

Graphing represents a key symbol system for scientific communication. Widely reported low graphing skills notwithstanding, middle school students can learn to communicate with graphs in the context of appropriate MBL investigations. Two early preliminary studies and a longitudinal study are reported that support this conclusion (Mokros & Tinker, 1987). In the three-month longitudinal study of MBL, students showed a significant gain on 16 graphing items, even though the instruction targeted science topics, not graphing skills. The first preliminary study attempted to locate graph-related misconceptions. Although graph-as-picture errors and slope/height confusions were identified, the ease with which MBL removes these problems calls into question the appropriateness of labelling them misconceptions. Four features of MBL seem to contribute to its success in facilitating graphical communication: MBL uses multiple modalities; it pairs, in real time, events with their symbolic graphical representations; it provides genuine scientific experiences; and it eliminates the drudgery of graph production.

The descriptive study was originally designed in a misconception framework. However, it does not seem to be helpful to describe the problems found as misconceptions. The graph-as-picture and slope/height confusion sets do not seem to satisfy the criteria usually applied to misconceptions. In particular, they are not resistant to proper instruction. The MBL instructional strategy appears to extinguish the sets quite easily. In as little as one forty minute intervention with the motion unit, much of the slope/ height confusion seems to be resolved. Misconception theory was useful in focusing attention on the cause for student problems and the search for appropriate instructional strategies. But, having found an effective instructional strategy, it seems inappropriate to label graph-as-picture and slope height confusion as misconceptions.

It is very likely the combination of these four factors (multimodal reinforcement, real-time linking of concrete and abstract, meaningful context, and elimination of drudgery) that contributes to the power of learning via MBL. When students are in control of a learning experience that they design, are given real time feedback about that experience, and are freed from the painstaking task of producing a graph, they are in an ideal position to learn what a graph says and means. As an incidental adjunct to their science investigations, confusions about graphs seem to be easily cleared up and graphs become a natural vehicle for expressing ideas about science.

10. Understanding of what components of MBL activities are proving effective

At the University of Maryland, one hour active-engagement tutorials using microcomputer based laboratory (MBL) equipment were substituted for traditional problem-solving recitations in introductory calculus-based mechanics classes for engineering students. The results of two specific tutorials, one on the concept of instantaneous velocity and one on Newton's third law were probed by using standard multiple choice questions and a free-response final exam question. A comparison of the results of eleven lecture classes taught by six different teachers with and without tutorials shows that the MBL tutorials resulted in a significant improvement compared to the traditional recitations when measured by carefully designed multiple choice problems (Redish et al., 1997). The free-response question showed that, although the tutorial students did somewhat better in recognizing and applying the concepts, there is still room for improvement. The MBL activities play a significant role in the improvement of student understanding of the concept of velocity. It is not simply the extra time that is responsible. Simply enhancing lectures is not effective in producing an improvement in the learning of the velocity concept for a significant number of students. It would be useful to have additional detailed experiments comparing different methods in order to build an understanding of exactly what components of MBL activities are proving effective.

11. New technology thus does not necessarily lead to better learning

Different cases of physics instructor’s implementations of Microcomputer Based Laboratory (MBL) in physics teaching have been studied. When implemented as a technological tool only poor learning results were observed while when MBL were used as both a technological and cognitive tool good learning results were observed (Bernhard, 2003). New technology thus does not necessarily lead to better learning. When developing and implementing computer aided learning we must focus as much on the cognitive aspects as on the technological aspects. Also we must focus on instructor's conceptions of teaching and learning since this affects their understanding of curricular reforms and lead to transformations of original developers educational intentions. When implemented as conceptual labs MBL achieves good learning results. However when MBL were used for formula verification labs, significantly poorer learning results were obtained. A detailed analysis of data has shown that the formula verification approach has been especially disadvantageous for female and for poorly prepared students.

Therefore it can be assumed that MBL doesn't automatically give good learning results. MBL-technology, and other forms of computer aided learning, cannot be implemented as only a technology. The educational implementation is of crucial importance and hence there is no definite answer to the common question if computers help to achieve "better" learning. Another conclusion is that we, when developing new curricula, must be as aware of instructor's conceptions of teaching, and learning as we in teaching and curriculum design must be aware of student's preconceptions.

Another research doubts on statement that data-logging exercises in science classrooms assume that with the proper scaffolding and provision of contexts by instructors, pupils are able to meaningfully comprehend the experimental variables under investigation. From a case study of knowing and learning in a fish hatchery using real-time computer statistical software Roth and Lee (2006) show that appreciating the distributions of fish weights and lengths were mediated by the practical understanding that comes from measuring and handling the animals over time. This prior knowledge was further mediated by the representations in mathematical forms where technology was central. Hence, as a fish culturist 'played' with the data logging-like technology, expanded forms of learning were made possible during the process of analysis and reflection. Besides clarifying the process of learning when using educational media like data loggers, researchers present the computer as a self-reflexive tool that constitutes—in a dialectical fashion—learning in the everyday world.

Researchers conclude that knowing about aspects of the world, about the variables pupils investigate in school science, requires learners to ontologically ground this experience of the material/social world *first* before they can begin making any sense of it. Subject of the study built her understanding of the statistical procedures and graph interpretation skills from her previous work of measuring fishes. On this account, it is thus presumptuous to think that teacher guidance alone can mediate better knowing using data loggers or related educational media, which is strictly a process that only learners can appropriate. This process can only be nurtured when the learning is embedded in everyday, routine activity

12. MBL make an understanding of physical phenomena more accessible

Microcomputer-based laboratory tools have the potential to help students develop a solid conceptual basis for understanding the world around them. Through the use of these materials, students' interactions with the physical world can be connected to the underlying principles that constitute scientific knowledge, thereby helping them to develop a conceptual, qualitative understanding that can be applied both inside and outside of the classroom. Students can use these tools to collect physical data that are graphed in real time and then can be manipulated and analyzed. The MBL tools have made possible discovery-based laboratory curricula that embody results from educational research. These curricula allow students to take an active role in their learning and encourage them to construct physical knowledge from observation of the physical world. The curricula encourage collaborative learning by taking advantage of the fact that MBL tools present data in an immediately understandable graphical form. The effectiveness of a kinematics curriculum compared to traditional college and university methods for helping students learn basic kinematics concepts has been evaluated by pre- and post-testing and by observation (Thornton & Sokoloff, 1990). There is strong evidence for significantly improved learning and retention by students who used the MBL materials, compared to those taught in lecture. The MBL tools give students the opportunity to do real science in the introductory physics course. Thus students can experience the excitement of the process of science the creative building and testing of models to explain the world around them. These tools give the science learner unprecedented power to explore, measure, and learn from the physical world.

Because of their ease of use and pedagogical effectiveness, they make an understanding of physical phenomena more accessible to the naive science learner and expand the investigations that more advanced students can undertake.

13. The real time graphing feature of the MBL seems to be effective

Extended Microcomputer-Based Laboratory (MBL) experience has been shown to be effective in improving middle-school students' graphing skills (Brasell, 1987). There is evidence that a treatment period as short as a single class period with a motion MBL unit was sufficient for high school physics students to improve their comprehension of distance and velocity graphs when compared with a pencil-and-paper graph-construction control treatment. Most of the improvement appears to be attributable to the real time graphing feature of the MBL. A delay of only 20-30 seconds in displaying the graphed data inhibited nearly all of the learning. In this research, the standard MBL activity is compared with one where the display of data is delayed until after all the data have been collected (i.e, the physical event has been completed). Then the data are displayed at the same rate as they were collected, thus effectively separating the real-time feature from dynamic property. This transforms the situation by separating in time the two elements that need to be linked, presenting them serially (or sequentially) rather than in parallel (or simultaneously). Activities were conceptually structured via worksheets to guide students in experimenting with the effect of changing the direction and speed of movement on distance-time and velocity-time graphs. Worksheets focused on the following concepts:

- Distance graphs are not the same as velocity graphs.
- When an object is moving at a steady (constant) speed, the line on a distance graph is sloping (nonzero slope) whereas the line on a velocity graph is flat (zero slope).
- Direction of the movement makes a difference to the slope of the line on a distance graph and the sign of the line on a velocity graph.
- When an object reverses direction, its instantaneous velocity is zero.

14. Worksheet-based experiments should not be recipe-like instructions

The unique affordances of datalogging are not being fully realised in science lessons because teachers are generally uncertain how to use dataloggers to enhance the learning of their students, and lack the skills and experience in facilitating inquiry-based science (Tan et al., 2005). Thus, it is not the datalogger technology that is the real focus of concern, but the vision of how the datalogger can be appropriately used, and the myriad of ways of how teachers can be supported in their use of dataloggers in their classes and in conducting inquiry-based science. The results of a national survey of 593 science teachers on the use of datalogging in Singapore secondary schools (Grades 7-10) and junior colleges (Grades 11-12) suggest that the unique affordances of datalogging are not being fully realised in science learning because teachers generally lack the vision for how dataloggers can be used to enhance the student learning experience in inquiry-based science.

Questions in an online survey included:

- the subjects and topics in which dataloggers were used,
- the types of tasks involving dataloggers,
- the teacher's role in datalogging activities,
- the pupil's role in datalogging activities,
- how pupils were prepared to use dataloggers,
- whether pupils were able to interpret data,
- whether inquiry-based activities were conducted, and if so, how were the inquiry-based activities were conducted,
- the support structures required for datalogging activities, and
- the difficulties teachers faced in conducting datalogging activities.

Time to deploy and setup, equipment access issues, perceived lack of relevance to the syllabus and scarcity of computers discouraged the non-users from using dataloggers. The most common use of dataloggers was in demonstrations and experiments. The majority of the examples (71.9%) were worksheet-based experiments where students followed instructions like a recipe from the worksheet to set up the experiment. Student investigations (14.7%) where the students had to plan their experiments themselves were a much less used.

15. Addressing conceptual understanding and making instruction more effective

A systematic investigation of the understanding of the concept of acceleration among students enrolled in a variety of introductory physics courses at the University of Washington has provided guidance for the design of curricular materials and instructional strategies (Trwbridge & McDermott, 1980). The criterion for assessing understanding of a kinematical concept is the ability to apply it successfully in interpreting simple motions of real objects. The main thrust of this study has been on the qualitative understanding of acceleration as a ratio. The primary data source has been the individual demonstration interview in which students are asked specific questions about simple motions they observe. Results are reported for the success of different student populations in comparing accelerations for two simultaneous motions. Failure to make a proper comparison was due to various conceptual difficulties which are identified and described. Some implications for instruction are briefly discussed. The conceptual difficulties with acceleration that were encountered by the students in the study appeared to be very persistent.

The authors have found the detailed information about conceptual understanding that has emerged particularly useful for helping some college students overcome deficiencies in preparation for introductory physics courses. The results of the study have made possible a concerted effort to address some of the specific difficulties that were identified. By contributing to knowledge of the ways in which students think about motion, this research has served to suggest new ways in which instruction may be made more effective.

16. Developing students' scientific reasoning skills

A microcomputer-based laboratory (MBL) curriculum was designed to develop students' scientific reasoning skills (Friedler et al., 1990). The corresponding research study investigated the impact of enhanced observation or enhanced prediction on scientific reasoning about heat energy and temperature problems. In two eighth-grade classes the instruction emphasized observation, while in the two other classes instruction emphasized prediction. The authors found equal gains for the observation and prediction conditions on a) subject matter knowledge, and b) ability to use scientific reasoning skills to solve problems. In contrast, those learning observation were better observers and those learning prediction became better at predicting results while solving problems.

17. Helping teachers to implement curriculum materials

In a research to identify some of the interacting factors which need to be addressed to manage the successful implementation of educational innovation was performed (Fullan 1991). Factors involved characteristics of the innovation itself (needs identification), goal clarity, complexity and the practicality of the innovation.

In a study, the feasibility and educational value of probe ware and associated instructional materials in middle school science education was addressed through consideration of costs, teacher professional development, and instructional design (Metcalf & Tinker, 2004). In order to test the approach, the authors developed 2 middle school science curriculum units, 6 low-cost probes that interface between handheld Palm computers, and CCLabBook software for the Palms that presents the curriculum, interfaces with the probes for data collection and visualization, and supports guided exploration. The materials were tested by 30 teachers in the first year, and in a follow-up study by 8 of those teachers the second year. The authors found that teachers were able to conduct the investigations successfully in their classrooms, and that student learning was enhanced through the use of the probes and handhelds. Specifically, students experienced the physical correlation between phenomenon and modeling, which helped them to develop understanding and to confront misconceptions.

Effect of MBL activities on students' knowledge was increased if students' previous knowledge of studied topics were low. The longer the period the MBL was used over, the greater the impact on students' knowledge. The improvement of students' knowledge was greatest in reading position versus time graphs (in "forces and motions" context) and understanding heat flow and graph reading skills (in "transfer of energy" context).
The teachers taking part in the research approved the used MBL tools and thought that the effects of activities on students were positive. They also intended to use the tools and activities in their future work. Teachers who adapted the given activities so that they would fit their needs succeeded in the use of MBL better than teachers who used

activities as they were given. The longer the MBL was used the better the students and teachers used MBL equipment the higher their engagement and lower their fustration. Students engaged the activities better if they could manipulate both the palm computer and the measurement probe. Students who only watched others manipulate the MBL were less engaged.

The use of MBL activities seemed to enhance students' learning of content. Teachers were able to implement the given materials to middle school education with help of either face-to-face or on-line instructions quite well. Students and teachers were able to succeed in almost every activity in TEEMSS project. Authors believe that TEEMSS material and technology created to implement it can be effective in science teaching.

A research in Tanzania was performed to answer the question: *What are the characteristics of an in-service arrangement that facilitates the implementation of MBL-supported lesson activities in the physics classroom?* (Tylia, 2003). To answer the research question a development research approach was employed. The strength of this approach is the opportunity to realize a series of small-scale examples of interventions and drawing up methodological guidelines for the design and evaluation of such products in an interactive manner. Teachers took on the role of science students, in which they were provided with opportunities to (1) reflect on their personal knowledge and prior experiences; (2) participated in interactive, hands-on and minds-on activities; (3) ask questions, solve problems, and use new knowledge; and (4) communicate and work with others in cooperative teams. In this way the exemplary lesson materials were effectively introduced, and teachers strengthened their content and pedagogical knowledge and skills. The following characteristics appeared to be essential in preparing teachers for such implementation:

- Flexible time for teachers to attend to in-service education, preventing clashes with their teaching schedules.
- Intensive and sustained in-service activities over longer periods of time lead to success in teacher learning and eventually good classroom practices.
- The workshops offered new and interesting knowledge and skills, preparing teachers to face the challenges in the real classroom situation. Moreover, the workshops stimulated teachers working collaboratively on concrete teaching

tasks.

- The exemplary lesson materials, enabling teachers to reflect on their learning, discuss their views with the researcher and suggest changes on the materials to make teaching more effective was seen as another contributing factor.

18. The use of MBL favours engagement with science concepts

By exploring the phenomenon of 'change of phase' of pure substances using a MBL system the authors examined how 1st year students (10th grade) of Greek Senior High School conceptualize the influence of the molecular weight of saturated fatty acids on the melting and the freezing point, during the 'change of phase' phenomenon (Pierrie et al., 2008). Results showed a statistically significant difference in every question. After the experiment more students responded correctly to all questions concerning the freezing point of the saturated fatty acids, the relationship of the freezing point to the molecular weight and the description of this relationship. This finding shows that the relationship between the freezing point and the molecular weight became clearer for the students after the experiment. It is also important to note that there was no statistically significant difference concerning students' responses and gender.

Based on the analysis of the researchers' field notes and the conversation between the students and the researcher, researchers formed the impression that most of them understood that during the 'change of phase' phenomenon there was no chemical reaction that led to the decomposition of the substance. The majority of the students, observing the experimental curves, seem to realize that the freezing point is not necessarily lower than the environment's temperature. Some students seemed to conceptualize the processes that take place at the microscopic level (changes of internal energy) and how they are related to macroscopic properties (melting-freezing point).

Data analysis of students' responses during the short, semi-structured interview for the evaluation of the procedure, showed students' preference for sensor use and computer assisted experiments over traditional lab experiments. They supported that using MBL system they can take many real-time and accurate measurements, and generate graphs at the same time.

Therefore, using a computer in a chemistry lab might provide students with faster and easier access to various information data, thus they have more time to deal with the concepts of the experiment. In conclusion, the MBL system, when used in appropriately established educational settings, might help students to comprehend more effectively the concepts being studied.

19. Combining the computer modeling to the practical work could be effective

Based on current theories of chemistry learning, it was intended to test a hypothesis that computer modeling enhanced hands-on chemistry laboratories are more effective than hands-on laboratories or computer modeling laboratories alone in facilitating high school students' understanding of chemistry concepts (Liu, 2006). Thirty-three high school chemistry students from a private all-girl high school in northeastern United States were divided into two groups to participate in a quasi-experimental study. Each group completed a particular sequence of computer modeling and hands-on laboratories plus pre-test and post-tests of conceptual understanding of gas laws. Each group also completed a survey of conceptions of scientific models. Nonparametric tests, i.e. Friedman's one-way analysis of ranks and Wilcoxon's signed ranks test, showed that the combined computer modeling and hands-on laboratories were more effective than either computer simulations or hands-on laboratory alone in promoting students' conceptual understanding of the gas law on the relationship between temperature and pressure. It was also found that student conception of scientific models as replicas is statistically significantly correlated with students' conceptual understanding of the particulate model of gases.

Combined probeware-based hands-on laboratory and internet-based computer modeling laboratory are more effective than either the probeware-based hands-on laboratory or the internet-based computer modeling laboratory alone to help students develop understanding of the gas law, i.e. the relationship between pressure and temperature. There is a statistically significant correlation between students' conceptions of scientific models as exact replicas and their understanding of the particulate mode of gases. Providing more time to study a chemical phenomenon by presenting different levels of representations (i.e. sub microscopic, symbolical and macroscopic) can help students to improve their understanding of the phenomenon. This improvement was limited to the mathematical relationship between pressure and temperature of a gas and the students' conceptual understanding of the particulate nature of gases did not change. A longer study with a larger sample could help to study the effect of combined practical work and molecular modelling to the students' understanding of particular model. Combining the computer modelling to the practical work could be effective as it allows students to study chemical phenomena on three levels of representation.

20. MBL activities to likely catalyse student construction of understanding

Teachers' failure to use the MBL more widely may be a result of not recognizing its capacity to transform laboratory activities (Russell et al., 2004). A research study aimed to increase understanding of how MBL activities designed to be consistent with a constructivist theory of learning support or constrain student construction of understanding. The first author conducted the research with his Year 11 physics class of 15 students. Analysis of students' discourse identified many instances in which students' initial understandings of thermal physics were mediated in multiple ways by the screen display. The findings are presented as eight assertions. Recommendations are made for developing pedagogical strategies incorporating MBL activities that will likely catalyse student construction of understanding.

The authors report the following results:

- First an attempt was made to identify the active elements in the MBL. Careful viewing of the video recordings from all cameras identified these as students, teacher, computer display (with its generating software), experimental apparatus (including the interface and sensors), and worksheet/POE notes.
- The dialog was read from the perspective that students generally progressed through five stages: (a) understanding the problem and predicting, (b) setting up and commencing the experiment, (c) collecting data and observing, (d) analysing, and (e) explaining the results. Reading and rereading the transcripts identified these five stages and confirmed they were appropriate and sufficient for analysis of the dialog.

From their analysis of results, the authors make the following eight assertions:

1. Students viewed the display predominantly as representing the experimental phenomena or other conceptual models related to the experiment, and occasionally as a graph in its own right.
2. During student–display interactions, while students' activities ranged from fulfilling

basic requirements to deep-level cognitive processing, the dyads completed the majority of tasks at a deep level of mental engagement.

3. During data logging, dyads generally engaged in multiple on-task activities related to making meaning of the graphs.
4. The enduring nature of the display was supportive of a deep approach to learning
5. Students critically evaluated the appearance of the graphic display.
6. Learning conditions in the MBL were conducive to fostering conceptual change: graphic evidence to engender dissatisfaction with prior conceptions; opportunities to construct new conceptions that were seen to be plausible, intelligible, and fruitful; and an atmosphere that was motivationally and socially conducive to constructing new understandings.
7. Within and between groups, students used the display as a shared resource to engage in a broad range of activities directed at interpreting graphs.
8. The teacher’s probing questions stimulated deeply processed responses linked to graph features and the experimental phenomena

This research provides encouragement for teachers who wish to realize some of the frequently promoted benefits of MBLs. It suggests that linking the familiar strategy of POE with the technological capacity of sensors and computers enables students to address their own understandings in effective ways. Students made informed judgments in accepting the display as a reliable artefact that made visible the bridge between unseen and subtle effects (temperature changes) and their physical causes (bench top models of the tasks). The MBL methods were supportive of a deep approach to learning, During the research the MBL display played the role of a pivotal actor (Table 1) in the social setting of the laboratory, in an atmosphere conducive to students’ conceptual development this research suggests that an effective way of catalysing Student construction of understanding may be to link the power and flexibility of MBL technology with established teaching strategies based on constructivist theories of learning.

In another study (Deng & al, 2011) two groups of grade 11 students were researched for the four-week period. Both groups studied Solution Chemistry unit which covered chemistry concepts such as electrolyte, ionization equilibrium, ionization of water, ion-product constant of water, pH, titration and hydrolysis of salt. The comparison group was taught with a teacher-oriented approach which consisted of lecturing and solving textbook problems. The experimental group was taught using constructivist-oriented data-logging based approach which consisted of two sub-categories: the Hypothesizing-Demonstration-Explanation-Application approach and the Hypothesizing-Planning-Regulation-Evaluation approach. The HDEA approach consisted of classroom activities in which the teacher created challenging questions for the students to answer. The HPRE approach was more student-centered and it required them to make hypotheses, plan how to test them and evaluate the hypotheses based on their inquiry. The data for the research was collected by pre and post tests of students' metacognitive abilities and post test of their conceptual understanding of two chemistry concepts: titration and hydrolysis.

21. Students' abilities for interpreting data are limited

Data-logging seems to be a suitable tool for teaching quantitative concepts. However, the relation between the target of the measurements and the other epistemic aspects of the measurements (object, device, and data) should be pointed out better to the students. To support this, the induction of local motives for measurements should be improved (van Eijck, 2006). In a study addressing data-logging the heart the author investigates how the use of ICT can contribute to an adequate method for teaching heart related quantitative concepts in pre-university biology education. The author reports that the students were able to improve the quality of the measured data by interpreting the visual qualities of the produced graphs. However, students had problems to connect the data produced to the functioning of the measurement probes. Also, the evaluation of the produced data based only on the visual qualities of the graphs without the need to discuss the target of the measurement activities.

Students were able to connect their measurements to the Wiggers diagram and to understand the limitations of their measurements. They weren't able to understand the Wiggers diagram as a average or idealization of multiple measurements and blamed the used MBL equipment for the differences between their graphs and Wiggers diagram. Students were able to interpret Wiggers diagram quite well. They had more difficulties to interpret parts of the diagram which didn't connect to any measurements they hadn't done personally.

Therefore, heart-related measurements should be applied for supporting the teaching of quantitative concepts, which have a clear relation with the quantities measured.

Preferably, the quantitative concepts to be taught should be observable in data which students obtained by themselves. The current design of the teaching sequence allowed students to interpret the data only visually. Neither the induced knowledge needs nor the activities after datalogging sufficiently helped the students to interpret the data at a more theoretical level

22. Using MBL in congruence with active participation in research activity

Given the central place IT-based research tools take in scientific research, the marginal role such tools currently play in science curricula is dissatisfying from the perspective of making students scientifically literate (van Eijck & Roth, 2007). To appropriately frame the role of IT-based research tools in science curricula, we propose a framework that is developed to understand the use of tools in human activity, namely cultural-historical activity theory (CHAT). Accordingly, IT-based research tools constitute central moments of scientific research activity and neither can be seen apart from its objectives, nor can it be considered apart from the cultural-historical determined forms of activity (praxis) in which human subjects participate. Based on empirical data involving students participating in research activity, we point out how an appropriate account of IT-based research tools involves subjects' use of tools with respect to the objectives of research activity and the contribution to the praxis of research. We propose to reconceptualize the role of IT-based research tools as contributing to scientific literacy if students apply these tools with respect to the objectives of the research activity and contribute to praxis of research by evaluating and modifying the application of these tools. We conclude this paper by sketching the educational implications of this reconceptualized role of IT-based research tools.

The way students used MBL equipment in the previous case study fit well on the theoretical framework writers of this article proposed. Students were able to use MBL equipment as tools to achieve their research goals. MBL tools helped them to perform graphical tasks quickly and concentrate on high-order goals of data analysis.

Students didn't use MBL tools independently or freely as the teacher often suggested ways to use tools and there was only a limited number of different kinds of data loggers and data analysis software available. Students' inquiry wasn't really free as it was limited by the context (physics class) and the equipment available. Students had several opportunities to evaluate the MBL tools they used in their research and were able to decide which way to use the tools in their research.

Research offer a framework for assessing if given activity allows students to use MBL tools "in congruence with active participation in research activity". Understanding the role of MBL tools in science through their own correct use of the tools could help students increase their scientific literacy. Using MBL activities to increase students' scientific literacy requires engaging students in authentic research. Simply performing the acts of research without understanding the objectives of their actions, or using MBL activities to learn scientific knowledge, won't increase students' scientific literacy. If the students can choose their research questions and the tools used, they may use them in a way that helps them to understand scientific work.

Reid-Griffin and Carter (2008) Examined the potential of technological tools by observing 7th and 8th grade middle school students' (n=23) use of portable data collection devices in a nine-week elective class, Exploring Technologies. Students were helped to learn how to use MBL equipment by using Cazden's three phases of scaffolding. The learning environment and the pedagogical approach allowed students to perform scientific experiment using technology as a tool. Cazden's model of three-phase scaffolding helped students to see MBL equipments as tools used in their activities instead of objects of their activities.

23. Chemistry students' challenges in using MBL's in science laboratories

Understanding students' challenges about using microcomputer based laboratories would provide important data in understanding the appropriateness of using MBLs in high school chemistry laboratories. Identifying students' concerns about this technology will in part help educators identify the obstacles to science learning when using this technology (Atar, 2002). MBL do not necessarily promote learning for all students. Some students may need extra help from the teacher in order to grasp the scientific concepts embedded in the MBL activities.

- Special attention should be given to slow pace learners.
- In order to keep the students actively engaged in the MBL activity it seems necessary that the teacher find effective ways of keeping students intellectually

busy.

- In an attempt to conduct experiments using MBL more effectively, teachers should constantly be on the look out for graph anomalies that may simply be resulted from misplug of probes into the interface.

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 (Aksela, 2011). 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. 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 metacognitive 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 that stimulates students' with right questions and tips.

24. CCL environment seems to positively effect students' learning outcomes

The main visualization component in the case-based computerized laboratory is graph representations in real time, while the ''hands-on'' aspect of the experiments adds another important component. The focus of a research study was to investigate 12th grade honors' chemical understanding and higher order thinking skills using both visual and textual means in the CCL learning environment (Dori & Sasson, 2008). The following research questions were addressed:

- What is the effect of the CCL environment on students' ability to bidirectionally express visual and textual chemical knowledge via: (a) describing, interpreting, constructing, comparing, and analysing graphs, and (b) expressing their chemical understanding through both graphs and text?
- What are the differences (if any) between experimental group and the control group in chemical understanding–retention and graphing skills?
- What are the characteristics of the visualizations aspects in the CCL environment

as expressed by students' reflection on the learning processes?

The findings emphasize the educational value of combining the case-based method with computerized laboratories for enhancing students' chemistry understanding and graphing skills, and for developing their ability to bidirectionally transfer between textual and visual representations. Furthermore, the research has shown that experimental students significantly improved their graphing skills scores in the postcase-based questionnaire compared with the precase-based questionnaire Because the CCL environment employed mainly two interventional tools including MBL technology and case studies, the improvement might be attributed not just to the use of real-time graphing, but also to the incorporation of case studies into the CCL curriculum.

For graph constructing and reasoning, the authors found a significant increase in the number and quality of chemistry understanding levels students invoked in the posttest questionnaire with respect to the pretest questionnaire. The improvement in students' graphing skills was observed at all three academic levels, with the low performers demonstrating the highest improvement and the high academic level students demonstrating a smaller yet impressive gain. The results validate the positive effect of the CCL (Case-based computerized Chemistry laboratory) environment on students' learning outcomes, in particular on the low performers. The replication indicates that our research findings are consistent and persistent.

25. Addressing an inquiry-based contextual approach with MBL technology

The focus of a study was on the investigation of the use of thematic inquiry-based tasks with active incorporation of mathematics, science, and microcomputer-based laboratory technology in standards-correlated activities that enhanced learning experiences. The activities involved students in two major contexts: forensic science investigations and environmental science issues (Espinoza & Quarless, 2010). The core of the project consisted of an analysis of students' proficiency in dealing with discipline specific content, and of their development of critical thinking process skills. Significant gains were observed in both content proficiency and improvement on critical thinking skills, most noticeably those involving meta-cognitive processes. An interesting and unexpected feature of tool use emerged from the data that provides exciting opportunities for further research. The results provide evidence that such an instructional approach can have a dramatic impact on the development of students' mastery of content and laboratory performance measures of the science material that they encounter.

There is an improvement on all process skills seen for the inquiry-based activities assessed during four different dates of the program; the specific improvement in process skills in order of significance (based on slope and correlation values) was: Inferring, Formulating Hypotheses, Interpreting Data, Identifying and Controlling Variables, Predicting, Measuring, Communicating, and Observing. The evidence from the study suggests that having laboratory experiences that are exploratory and thematic will help students to develop the necessary critical thinking skills needed to succeed in future science courses, and effectively addresses the need for better preparation to develop scientific literacy.

The authors list the specific ways in which they believe this happens:

- By engaging students in tasks where the content is addressed as part of an investigation;
- By engaging students in the inquiry process of scientific methodology to facilitate facile and balanced development and exploration of their "tool" knowledge (in this case the instructional technology) as linked to the investigation;
- By allowing students to use critical thinking skills such as predictions, inferences, data analyses, and reflections in exploring relationships between variables;
- By requiring use of multiple representations of information (such as graphical, verbal, and symbolic) as they attempt to solve problems within a larger setting;
- By the existence of a positive correlation between thematic context and performance;
- By the use of the Normalized Content Gains > STDEV, which seem to provide a good "quick test" that correlates the effectiveness of the instructional tool with content gains (coherence between tool, content and context).

The authors give the following recommendations for future research:

- Develop an assessment tool that provides better coherence between context, content(concepts) and the instructional tool;

- Develop a closer or more relevant application to a new context (different application/different representation); and
- While the “tool” is not the object of the learning, more attention must be given to how “tool” knowledge impacts on concept development (content).

Chatterjee and his colleagues came in 2009 with quite strong quantitative data. In spring semester 2005, 703 students (274 male, 429 female) of general chemistry at Texas A&M University took laboratory course where eight experiments were guided-inquiry designed and two were open-inquiry designed. The guided-inquiry laboratories and worksheets corresponded to approach in which student follow experimental directions, gather data on certain specified variables, and through the analysis process establish relationship among the variables from their own data. In open-inquiry laboratories students design and perform their own procedures to investigate a question. These laboratories apply the relationships previously developed via guided inquiry activities in a new setting or examine a new aspect of that relationship. The study wanted to answer, (1) if students can differentiate between a guided-inquiry laboratory and an open-inquiry laboratory, (2) what are the attitudes of student toward guided-inquiry laboratories and open-inquiry laboratories, (3) whether students think they can learn more with guided-inquiry laboratory or open-inquiry laboratory. Surprisingly, less than half of the students could identify both the guided and open inquiry lab (45.8 %) after reading five scenarios describing the experiment performed guided or open. More often students had difficulties to identify inquiry labs. The results to research question two students had a more positive attitude toward guided-inquiry laboratories they preferred to have procedures included in the laboratory manuals. Nevertheless students felt they had a lot of thinking and analyzing for guided-inquiry laboratory reports, but at the same time they considered laboratory reports as more easy that took less time and effort and the labs were fun to do. Almost three quarters would prefer guided-inquiry. The reason may be time requirement. Student performing open-inquiry labs have to developed a procedure that is possible to do in a specified amount of time and will also give the required results; after the lab students have to write a formal laboratory report that is not necessary in case of guided-inquiry where students are given formal instructions. Still, students had to answer multi-page analysis section of laboratory reports. Students themselves think (research question 3) they can learn more with guided-inquiry laboratories (45.96 %) while 22.05 % think they can learn more in open-inquiry laboratories.

26. Combining simulation with data processing and analysis

The topic of acid-base reactions is a regular component of many chemistry curricula that requires integrated understanding of various areas of introductory chemistry. Many students have considerable difficulties understanding the concepts and processes involved. It has been suggested and confirmed by research that students may be benefit from computer-supported activities such as data logging, simulation and modelling. In this paper the authors review the different methods of using computer acquisition and modelling to examine acid-base titration and we discuss how a versatile, integrated computer learning environment can be successfully applied to this end (Heck et al., 2009). The environment integrates, amongst other things, measurement, a control tool, and a modelling tool. In their work the authors discuss concrete examples, taken from an in-service teacher training course and culminating in the student practical investigation of analysis of acid in soft drinks. For example, they discuss the design of instructional materials and the didactical approach of integrating data logging and modelling in acid-base chemistry education.

For the developed activities to be effective for teaching and learning, it is helpful for teacher to consider two types of skills in using computer learning environment:

- Operational skills, which concern the manipulating of the computer hardware and knowledge of the features in the software.
- Procedural skills, which concern the manner in which the software tools are employed in the lesson context for the purpose of achieving learning benefits. A dominant aspect is the development of an inquiry approach.

For the teacher there are further pedagogical skills which contribute to the effectiveness of the activities:

- Making clear the learning objectives for each activity
- Understanding of the special value for the ICT method and exploiting its full

potential in purposeful ways.

- Managing the activity in a way which promotes appropriate rather than indiscriminate use of ICT
- Identifying of opportunities to exploit aspects of data logging and modelling for developing higher order interpretative skills in experimental science.
- Integrating the learning from each activity with previous knowledge and skills to enhance students understanding of the acid-base topic and titration in particular.

The authors summarize the potential learning benefits ICT value of datalogging (graph in real time, shape of titration linked to the strength of acid, difference equivalence and neutral point, analysis tool allows detailed investigation of the data, processing tools allow calculate [H3O+], high quality data), and of modelling (calculate [H+], [OH-] and pH changes, models used as simulations, modelling provides visual dynamics for abstract concepts, students get an idea of the descriptive and predictive quality of models, get a better view of use of models in chemistry). Simulation combined with data processing and analysis enhances the learning of abstract concepts like buffer strength.

27. An inquiry-oriented approach for making the best use of ICT in the classroom

Authors conceive ICT as tools that can enhance particular learning situations or environments, and in this sense, the article elaborates on the most appropriate technologies for particular learning environments and discusses in what order, and with what purpose, these technologies should be used (Pintó et al., 2010). The first part of the paper highlights the most commonly used technologies in science classrooms, reviewing the unique opportunities they offer that would not be possible otherwise. The second part of the article presents a proposal for using some of them in a specific pedagogical context: an inquiry-based learning cycle for laboratory work.

What and how should ICT be used so that they contribute to better learning in the science classroom?

- How can a certain teaching and learning approach, such as inquiry-based learning, be enriched by the use of ICTs in the science classroom?
- How can a certain teaching and learning situation, such as school laboratory

work, be enriched by the use of ICTs in the science classroom?

From the authors' point of view, the most interesting ICT tools for those inquiry activities that explicitly include laboratory work are: computer simulation and modeling tools, data-logging and video analysis tools, and tools for representing and organising knowledge. The authors propose and explain a basic inquiry cycle for laboratory work in science education, including ways of using these ICT tools to enhance the learning potential of this cycle. Their point of view is that the aim for including these ICT tools is not only for a better learning of science contents and skills involved, but also for greater achievement of digital competence and a more sophisticated idea of how real science is done in ICT-enhanced laboratories. Finally authors present a practical case of the use of the laboratory work inquiry cycle using some ICT. The authors argument that the learning potential envisaged for ICT tools in science classes depends on the particular characteristics of the ICTs used, but also on using them within a particular learning approach, in a particular setting, with a particular aim and in a particular sequence. In this sense, they have clarified the sort of learning possible with each of these tools and we have offered a possible model or sequence for their use in laboratory work following an inquiry-based learning cycle.

More researches in the field are claimed, that could lead to the elaboration of a set of strategies and models, such as the cycle proposed here, useful for guiding teaching and learning that really benefits from the potential that ICTs can bring to the field of science education.

28. How students manage MBL equipment to learn chemistry

The author presents a chemistry activity for secondary school students in which learners work using pH and temperature sensors (Tortosa, 2007). The activity is designed as an inquiry-guided learning cycle. Students from several secondary schools, with no previous experience in MBL equipment, come to University to perform the laboratory session using sensors. It is studied how students deal with sensors the first time they use them. The results show that more than 70% of the students can use MBL in an efficient way with very little help or no help at all. About 70% of students who had not previously worked with MBL equipment are able to properly configure the system to obtain experimental data with a sensor; half of these students (35.4%) worked autonomously using only written instructions and the other half .could do it with a little help from the teacher. Approximately 60% of students, inexperienced in the use of MBL, properly configured the software to correctly display the results of measurements with two sensors. The number of autonomous students is slightly lower (27.8%) than those who need help to perform this action (31.6%). It is worth noting that about 20% of students in the two cases studied (19.0% and 22.7%), show no interest in manipulating the computer for proper data collection and perform other tasks while their peer group concerned with computing device. In the work, inexperienced students in the use of MBL were observed when configuring the device. The work shows that most of them can do it with no or little help. There are a fifth of students who seemed not having interest in configuring the equipment, as they didn't participate in this part of the activiry.

***29. U*sing sensors in chemistry lessons to promote significant learning**

To understand the students' awareness after performing a chemistry workshop designed as an inquiry guided learning cycle, and using MBL equipment to data capture, authors analyse students' answers in the lab sheets and in an anonymous questionnaire administered at the end of the activity (Tortosa et al., 2008). From these writings, authors conclude that students understand the main chemical concepts worked in the session, that more than half of learners they give sense to a new concept introduced in the session and that students give more importance to the concepts than equipment used to obtain experimental results. In order to understand the students' awareness after performing an inquiry-guided chemistry workshop using MBL, the authors addressed the research questions:

1. What are the students' views of the work done in a long laboratory session using MBL?
2. Are they able to make sense of the new concepts which have only been introduced in the workshop?

When the students explained what they had done during a long laboratory chemistry session using MBL in an inquiry-guided learning-cycle, authors found that:

- They refer to most of the chemistry concepts used during the session.
- The concepts mentioned, ordered by its frequency, were pH, buffer solutions, chemical equilibrium, acids and bases and quotidian/blood buffers. Chemical

equilibrium is the less mentioned concept that students refer to and displacement of chemical equilibrium was not mentioned

- Students not only were able to explain their work alluding to chemical concepts, but many of them made sentences integrating MBL or other laboratory devices in the activities done. We worked with pH and buffer solutions. We added acid and base to a buffer solution with distilled water and we observed with pH sensors what happened.
- Students considered MBL and other equipment as simple instruments, and didn't attract specially their attention. None of the answers has referred only to the MBL or other laboratory instruments usage.

After performing an inquiry-guided taught chemistry session using MBL, designed as a learning-cycle, and studying the answers of students, the authors conclude that:

- Students are able to mention the core concepts of the workshop.
- When students mentioned MBL technology, they integrate this device as a mechanism to progress in the inquiry sequence. No answers have been only related to MBL or to computer use, that is students have given higher priority to the chemical concepts rather than the technological tools that record and display the data.
- A particular new concept introduced only along the session in a learning cycle approach could be used properly for about half of students we could consider it as a positive success of the approach given to the session. Further studies should be done about it.

30. Students' understanding of acid, base and pH concepts

In the study the effectiveness of pH indicators, pH meter and MBL equipment in the understanding of the concepts of acid, base and pH is compared (Nakhleh & Krajcik, 1994). 15 students are divided in three groups of 5. Each group works using a different technology. A semi-structured interview is administered to students Researchers compare the evolution of each student and of the group using studying concept maps.

Two areas of interest were targeted: the change in the students' understanding of acids, bases and pH over the course of the treatment and the type of thought processes in which the students engaged while performing the treatment tasks. These understandings and thought processes were followed as function of three levels of information presented by the technology: low level as represented by the use of chemical indicator solutions, intermediate level as represented by the use of a pH meter, and high level as represented by the use of a microcomputer-interfaced electronic pH probe. In this paper, authors report on students' understandings prior to and after interacting with these technologies.

Researchers find two general conclusions. First, students using microcomputer-based laboratory activities appeared to construct more powerful and more meaningful chemical concepts. Second, the microcomputer group's high rates for both erroneous and acceptable links provide evidence that these students were positively engaged in restructuring their critical knowledge.

31. MBL can help to learn cross-curricular themes

As Physics, Biology and Chemistry are all Natural Sciences it can be also interesting to find ways how to make genuine connections between them in educational process. Some researchers (Sorgo & Hajdinjak & Briški, 2008) show that MBL is a promising way how to do that. There are many individual chemical or physical processes were both chemical and physical properties can be experimentally measured together. Biological processes in addition to its biological aspects have also those two physical and chemical aspects. Therefore, the biological processes are probably the most appropriate to cover all three of them (biological-chemical-physical) together. As the authors showed in their research computer-based laboratory can be very helpful to organize such a hard challenge.

In the study the authors prepared a series of model experiments illustrating the journey of a sandwich through the digestive system. Using a computer equipped with a commercially available data-acquisition system and a couple of sensors, they illustrated the basic underlying physical and chemical principles of a biological process (digestion) to the students. Students were able to investigate, through hands-on activities, the chewing force of the jaws, importance of the mechanical breakdown of food, enzymatic activity of pepsin and amylase, antibacterial activity of hydrochloric acid, and importance of the villi for absorption.

As the authors referred such types of laboratory exercises could be designed as a mixture of biological, physical and chemical partial experiments with an overall effect on students' natural science knowledge development. However, there are several obstacles to organize such learning. The first one is the choice of partial experiments were the teacher has to assure that the physical, chemical and biological knowledge of students needed to comprehend the experiment is in a necessary level. The second obstacle is related to difficulty of organizing such three-subject learning. The third obstacle is that many activities concerning teaching about human physiology are unsuitable for classroom use, at least at the pre-university level, because of health issues, ethical concerns, and the possibility of exposing private or intimate data.

In the 32 tested students' point of view the research mostly uncovered that:

- students found the experiments interesting and helpful for understanding the (biological) digestive process because the process was learnt from different viewing angles,
- from the perspective of gaining knowledge through laboratory activity, it seems that students know the goals of the experiments and that they understand the graphs,
- the students needed help to make connections between what was seen and what it all means.

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