AC 2010-799: INVOLVING HIGH SCHOOL STUDENTS IN CONSTRUCTING AND USING DEVICES FOR AUTOMATION OF CHEMISTRY LABORATORY

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Involving High School Students in Constructing and Using Devices for Automation of Chemistry Laboratory

Abstract

Computerized systems which include data loggers and sensors have been introduced recently in high school chemistry laboratories. The systems provide automation of collecting, processing, and communicating data, however hands-on manipulations are performed manually. This paper proposes additional automation of basic manual laboratory operations and construction and use of two devices, developed in our study: an automatic titrator, and a computer controlled dispenser. We present results of pilot implementation of the proposed approach in high school chemistry laboratory classes. As found, the use of the automation devices enabled to save time needed for performing laboratory work and devote it to inquiry activities. The automation devices increased accuracy and precision of the measurements. The students participated in the study noted that experiments in the proposed automated environment required less time, were more accurate, convenient and safety. They appreciated the opportunity to use advanced technology and have more time for inquiry activities.

Introduction

Rapid development of automation technologies cardinally changes experimentation in chemistry research laboratories[1]. Information management systems automate collecting and analyzing data of chemical experiments and communication of results thereby freeing laboratory stuff from routine manual operations.

Laboratory automation courses have been introduced in undergraduate and graduate chemistry curricula[2]. A number of papers report on applying industrial titrators[3] or constructing an automated titrator based on industrial automated devices, such as an automated pipette[4], a metering pump[5], or a computer-controlled syringe pump[6]. Some earlier studies reported original prototypes of construct constant rate burettes.

Recently the automation trend has involved high school chemistry laboratories. In Israel the Advanced Chemistry discipline includes a unit "Computerized Laboratory" in which the learning environment provides to students automation in experimental data collection and analysis by means of sensors, data loggers and computers[7]. Educational studies indicated the positive effect of this practice on fostering higher order thinking skills of the students.

In this study we constructed an automatic titrator and a computer controlled dispenser and followed up their use by high school students in chemistry laboratory experiments. The Student Learning Environment Inventory (SLEI)[8] was employed in order to examine students' perceptions of a learning environment which integrates the automation devices in basic chemical experiments.

Automation System Development

While in the conventional chemistry laboratory experiment the learner deals with the reactor and reagents directly, in the computerized laboratory[7] this connection is mediated by the technological chain: *learner – computer – data logger – sensors – reactor – reagents*. This chain provides the learner with automated data collection and processing.

In this paper we propose to make the next step in automation of the school chemistry laboratory – to integrate the computerized laboratory with devices providing automation of manual operations. Introducing the *automated devices* enables computer controlled supply of *reagents* and real-time synchronization between manipulation, measurement and data collection. In this architecture the computer not only collects and processes data but also controls the automation devices, as presented below.

Devices

We use the MultilogPro data logger connected to PC, or the NOVA 5000 computer with built-in data logger, both of Fourier Systems (www.fourier-sys.com). The sensors of Fourier and Vernier are applied (www.vernier.com/choosecountry.html?path=/).

The automation devices have been developed using the modular robot construction kit Robix (www.robix.com) and other mechanical, electronic, and laboratory components. These devices are driven by the servo motors which are connected to the host computer through the electronics interface. The software supports a script language for generating point-to-point motion sequences. In this paper we describe two automation devices developed in our study: a computer controlled dispenser and an automatic titrator.

Computer Controlled Dispenser

Taking aliquots by the Moore pipette requires time, high attention and manual skills, the lack of which causes errors in students' experiments[9]. We developed and implemented a simple automatic dispenser (see Figure 1).

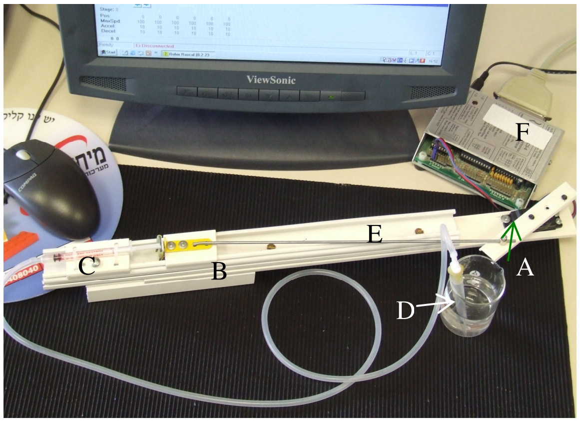

Figure 1. A. Servo motor; B. Plastic rail; C. Syringe; D. Tip; E Crank; F Interface.

The device is a slider-crank mechanism constructed out of a servo motor A, plastic rail B, syringe C, and tip D. The servo motor uses this mechanism to move the syringe piston in order to take the aliquot. The motor is controlled by computer through the Robix electronics interface F. The user can define by coordinates initial and final positions for the syringe piston movement that provide taking the needed aliquot volume. In our experiments we programmed the dispenser for taking 1 ml aliquot, providing complete filling and evacuation of solutions from the tip.

Automatic Titrator

The automatic titration system consists of a constant delivery rate titration device, stopcock, capillary injector, NOVA 5000 computer and sensors, as presented in Figure 3. The constant delivery rate titration device consists of the air pump, air reservoir, and titrant tank. The air pump provides the air reservoir with 104.0 kPa constant pressure which is safe for students' experimentation (102.6% of the normal atmospheric pressure). The titrant tank is connected by a silicon tube to the pressure source - air reservoir. Another silicon tube is submerged in the titrant solution and connected through the stopcock to the capillary injector. The air pressure extrudes the titrant solution from the tank to the capillary injector when the stopcock is open. During the titration process the capillary injector (inner diameter 0.1 mm) injects the titrant to the reactor, being submerged in the titrated solution. This is done in order to avoid "drop error" effects (Kirk, 2007). The titrant solution is not flowing into the reactor when the capillary injector is submerged in the titrated solution and the stopcock is closed.

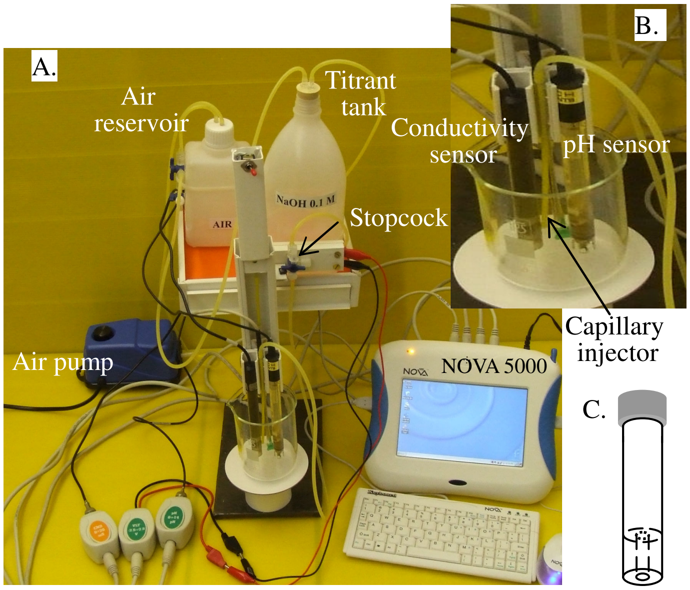

Figure 2. The automated titration system: A. General view;
B. Reactor and sensors; C. Injector

All the components of the automatic titration system, except the NOVA 5000 computer and sensors, are developed or modified by the authors. One of the technical problems was to synchronize the moments of opening the stopcock and beginning measurements by pH and/or conductivity sensors. The simultaneous start of injecting the titrant and data collection in the experiment is achieved using the indicator - a simple electronic circuit consisted of a push button switch, a battery, and a voltmeter sensor connected to NOVA 5000. At the moment of manual turning on the tap of the stopcock, it releases the push button switch, thus breaking the circuit. The voltmeter registers the resulted voltage fall and sends the input signal to NOVA 5000 operating standing in the triggering run mode. When receiving the input signal NOVA 5000 starts sensor measurement and data processing.

The automated titration procedure is as follows:

- To take aliquot of the titrated solution by the computer controlled dispenser to the beaker and add distilled water.
- To submerge the pH sensor and injector into the titrated solution (in the beaker) and turn on the stirrer.
- To run the data collection program on NOVA 5000 and turn on the stopcock.
- To follow up the screen representation of the titration process and detect the equivalence point.
- To stop the program, close the stopcock, take out and wash the pH sensor and injector.

The graph of titration displayed on the screen is presented in Figure 3. After determining the equivalence point from the pH derivative graph and the titration period from the voltage graph, the titrated solution concentration is calculated.

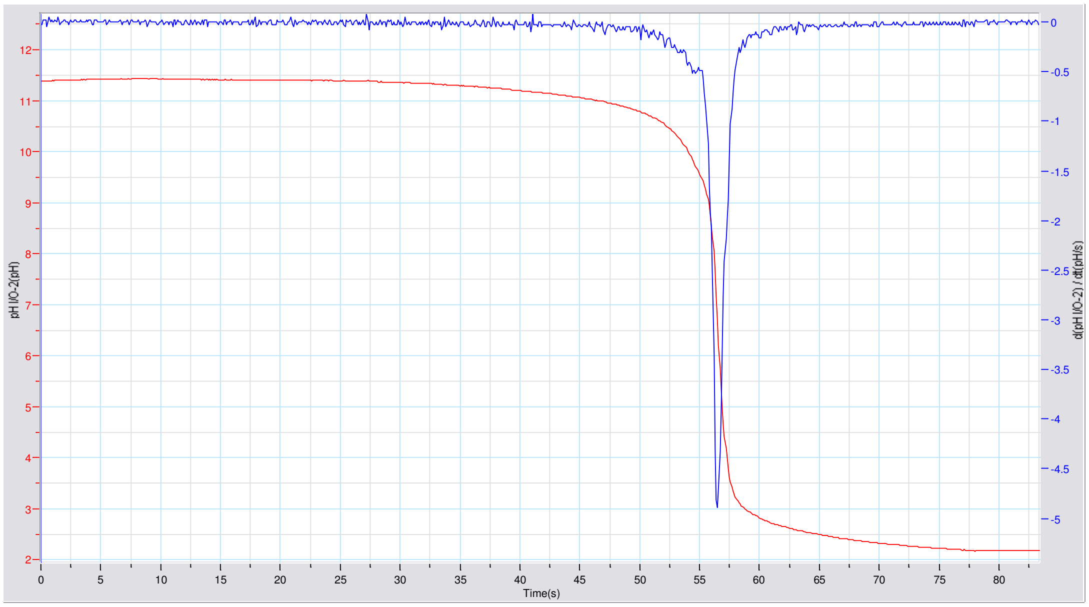

Figure 3. The graph of pH (red) as functions of time and its derivative (blue)

Automated titration enables to avoid the following "types of errors" of manual titration (see http://www.titrations.info/titration-errors):

- Indicator error in end point detection.
- Volumetric glass inaccuracy (burette and pipette).

- Insufficiently large volumes of titrant and titrated solutions.
- Human errors (misjudging the color of the indicator near the end point, misreading the volume, lack of skills of using burette and pipette, incorrect meniscus leveling.

Implementation at School Laboratory

The described automation devices were used for teaching the Case-Based Computerized Laboratory subject as part of the Chemistry course for secondary schools. The subject was taught in 2006-2007 school year to eleventh grade (N=30) and twelfth grade (N=24) students. Both groups studied and conducted titration experiments in which data collecting and analysis were automated by the data logger system, while titration manipulations were performed in two modes: manually and with the automated titrator and dispenser.

The laboratory work in the manual and automated modes was compared by means of chronometering titration manipulations, as shown in Table 1. The data in Table 1 indicate that using the automation devices significantly reduces time needed for performing titration laboratory work. When taking aliquots by means of the automated dispenser the student does not need to concentrate on coordination of her/his visual perception and hand operation in order to fix the meniscus at eye level. The operation of filling the burette in the automated mode is omitted and thus, many errors typical for inexperienced students are avoided. In this mode there is no need to perform the first "rough" titration and the following automated titrations also take less time than manual.

Table 1. Chronometering titration laboratory (in minutes)

Operation	Manual manipulation time	Automated manipulations
Taking 3 aliquots	10	3
Filling the burette (3 times)	5	0
Titration of the first aliquot	10	3
Titration of second and third aliquot	10	6
Calculating the result	10+ at home	10
Total	45	22

Our goal in introducing automated titration was twofold:

1. To save laboratory time spent for manual operations and use it for activities focused on better understanding of the subject matter.
2. To increase students' motivation to study chemistry through experimentation by providing them with advanced learning environment that integrates modern computer-based automation technology.

To address the first goal we compared students' activities performed in the computerized laboratories with and without automation devices. The activities during 45 minutes of the lesson without automation devices are listed in the second column of Table 1. As follows from the third column of the table, the same work with automation devices took only 22 minutes. The students used the rest time for inquiry activities required by the curriculum from advanced level chemistry laboratories. Accordingly, each group of the students has to formulate at least five research questions related to the studied phenomenon, discuss them and plan their own new experiment aimed to answer one of the questions. In the discussions with participation of the teacher the students considered different aspects of the phenomena, some of which were beyond the curriculum. In contrast, the groups that conducted the titration experiment manually had to leave the inquiry activities for the next laboratory lesson.

In 2007-2008 the subject was taught to the twelfth grade class of 36 students with titration experiments conducted in the manual and automation modes. We evaluated the effect of introducing the automation devices on students' motivation to study chemistry by means of the post-course questionnaire which consisted of two parts. The first part was the actual version of the Science Laboratory Environment Inventory (SLEI) [8]. This questionnaire examined students' attitudes towards the laboratory environment. The SLEI questionnaire consists of 35 items grouped in five categories presented in the first column of Table 2. The second column includes sample items for each of the categories. The level of agreement with each of the items is responded on the five-point scale: 1 = Almost Never, 2 = Seldom, 3 = Sometimes, 4 = Often, 5 = Very Often.

Table 2. Scales and sample items of SLEI.

Category	Sample Item
Student cohesiveness	Students work cooperatively in laboratory sessions.
Open-endedness	In our laboratory sessions, different students do different experiments
Integration	The laboratory work is unrelated to the topics that we are studying in our science class
Rule clarity	Our laboratory class has clear rules to guide student activities
Material environment	The equipment and materials that students need for laboratory activities are readily available

We analyzed the students' attitudes through comparison of our results with other studies[8, 10, 11], in which different types of chemistry laboratory environments in Israeli high schools were evaluated using the SLEI instrument. Hofstein et al.[8] considered a close-ended laboratory without computers, inquiry activities and automation. Attitudes towards the inquiry based laboratory were examined by Hofstein et al.[1], and towards the case-based computerized laboratory by Marjieh[11]. The mean grades assigned to the five categories of the SLEI in our study and in the three abovementioned studies are presented in Table 3.

Table 3. Results of the SLEI test in our and other studies

Laboratory Type / Categories of SLEI	Close-ended laboratory [8]	Inquiry laboratory [10]	Case-based computerized laboratory [11]	Our results
Student cohesiveness	3.80	3.87	3.90	4.25
Open-endedness	2.20	3.27	2.57	3.47
Integration	4.20	4.08	3.70	3.41
Rule clarity	3.62	3.69	3.74	3.85
Material environment	3.55	3.71	3.88	3.87

The table indicates that the evaluations of our chemistry laboratory environment in all the categories, except one (Integration), are higher than of the other environments. The lowest evaluations were given to the close-ended laboratory[8]. A possible explanation for higher evaluations of the automated environment is that it reduces time needed for the experiment and utilizes it for further inquiry activities. It combines advantages of computerized data collection and analysis, automation of manual operations and self-directed experimentation.

The mean grade for the Integration category given to our laboratory is lower than to other laboratories possibly because in our case chemistry laboratory was studied following the new curriculum which did not provide coordination between laboratory sessions and related theoretical studies.

The questions in the second part of the survey tested students' degree of consent with the assertions related to using the automation devices. The following eight assertions were extracted from interviews with the students participated in our study in 2006-2007:

- The experiment aided by the automation devices is more rapid.
- The use of automation devices yields more accurate results.
- The experiment with application of the automation devices is similar to an industry laboratory test.
- Practice with the automation devices allows the students to acquire skills important for their future careers.
- The experiment by means of the automation devices is more convenient to perform.
- Integrating the automation devices creates opportunities for students’ participation in planning their laboratory activities.
- The automated devises make the experiment more safety.
- It is important to me that we use advanced technology devices.

Students' opinions about these assertions are summarized in Figure 4. The diagram shows high positive evaluation of using the automation devices by the students. The fact that the highest evaluation 4.5 (out of 5) was assigned to the importance of using advanced technology devices points to the attractiveness of the laboratory automation. The majority of students noticed that experiments with automation devices are more convenient, rapid, accurate, and safety, impart skills of working in automated environments. With this, high positive results the comparatively lower evaluation of the third assertion reflects that the students do not associate the developed devices with that used in industry laboratory.

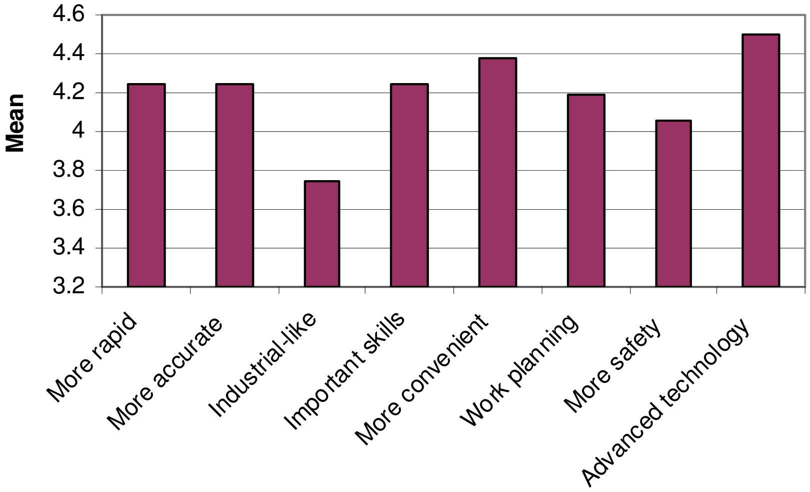

Figure 4. Evaluation of using automation devices

These findings are in line with students' reflections collected by interviews. A typical student's response:

> *"In the automated laboratory receiving titration was more simple and faster as compared to the manual experiments, our preference is certainly, performing titration with convenient automated equipment".*

In the interviews the students also noted that the automated titration experiment is more simple and significantly faster, experimental results in this mode are more accurate because the control is not by eyeballing. The students were very positive about automation of manual operations in their laboratory practice. Many of the students expressed interest and motivation in studying automation and participation in designing and building automation devices.

Conclusion

Our experience of creating simple affordable automation devices, their integration with a data logging system and teaching automated laboratories indicates the considerable potential of this technology for improving experiential chemistry education in high schools.

Application of the developed devices enables to save time spent for performing manual operations and focus the laboratory on inquiry activities. It also enables to raise the accuracy and safety of the experiments by eliminating errors and incidents related to manual operations.

The educational study showed laboratory automation as an important factor for motivating students to study chemistry through experimentation. Results of the SLEI test in our study provide first indications that the integration of the automation devices contributes to positive attitudes towards the laboratory environment. The students certainly prefer laboratory environments which exploit modern technology. Based on students' feedback, we hope that additional educational benefits can be achieved by introducing additional automated devices and through involving students in their creation.

Acknowledgments

This work was supported by the American Technion Society Research Grant. Data logging devices were granted for the experiments by the Fourier Systems Co. The authors thank Prof. Judy Dori for support.

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