Effects of Students' Pre- and Post- Laboratory Concept Maps on Students' Attitudes toward Chemistry Laboratory in University General Chemistry*

Ziya KILIÇ[1], Osman Nafiz KAYA[2] & Alev DOĞAN[2]

[1] Gazi University, Gazi Faculty of Education, Department of Chemistry Education, Ankara, TURKEY

[2] Gazi University, Gazi Faculty of Education, Department of Science Education, Ankara, TURKEY

Abstract: The purpose of this study was to investigate the effects of scientific discussions based on student-constructed pre- and post-laboratory concept maps on students' attitudes toward chemistry laboratory in the university general chemistry. As part of instruction, during the first four laboratory sessions, students were taught how to construct and objectively score concept maps using a scoring scheme with a symbol system. Then, students were required personally to construct a map prior (pre) and after (post) each of the five laboratory experiments. Concept mapping was used as a tool to carry out the scientific discussions about chemical concepts involved in general chemistry laboratory experiments between instructors and students, and among students. In the experimental group, students (N=45) performed their general chemistry laboratory experiments using individual, small and large group discussions based on pre- and post- laboratory concept maps, whereas the control group students (N=46) performed their laboratory investigations using traditional approaches. A questionnaire of attitudes toward chemistry laboratory (QATCL) developed by the researchers was administrated to both groups to determine the pre-existing differences between the two groups as a pre-test. At the end of the study, QATCL was re-administered to all of the students in both groups to analyze the effect of the intervention on students' attitudes toward chemistry laboratory. The data were analyzed using analysis of covariance (ANCOVA). The statistical results of the QATCL post-test scores showed that there was a significant difference favoring the experimental group. Hence, it is concluded that scientific discussions founded on pre- and post-laboratory concept maps are more effective in improving students' attitudes toward chemistry laboratory than traditional teaching.

* Poster presented at 18th International Conference on Chemical Education "Chemistry Education for the Modern World", İstanbul, TURKEY, 2004.

Introduction

Instruction in general chemistry laboratory at Universities in Turkey is generally carried out through expository approaches, which consist of students following directions to arrive at a predetermined outcome, to illustrate an important reaction, and to verify a principle or theory. Such expository laboratory activities that have a “cookbook” nature do not foster conceptual understanding, critical thinking skills, and student learning (Domin, 1999a,b). Assessments of the PSTs’ conceptual understanding in the chemistry laboratory have been primarily done through small quizzes before each laboratory session and laboratory reports. The small quizzes taking 10-15 minutes generally consist of short-answer questions related to key concepts of the laboratory investigations that will be performed by the teacher candidates. The laboratory reports covering the 20-25% of the laboratory grade have been prepared by the teacher candidates in an outline format of their laboratory investigations. The teacher candidates do not need to take a midterm exam because the means of these small quizzes are used as a grade of the midterm exam, but they must take a final exam consisting of open-ended questions, the multiple-choice tests, short-answer and fill in the blank format questions. The final exam for the chemistry laboratory course generally takes about one hour. These kinds of assessments for students’ conceptual understanding in the chemistry laboratory may be considered as compatible with the teaching and instruction in the laboratory because this kind of educational environment can be characterized as instructional approach-knowledge transmission; learning approach-rote memorization; and assessment procedure-standardized testing (Birenbaum, 2003). Our purpose by these tests is to differentiate between the PSTs and rank them according to their achievement in the chemistry laboratory.

It should be also noted that this kind of learning environment at general chemistry laboratory composing of traditional teaching and testing is common in the entire world (Domin, 1999a,b). For example, Abraham et al. (1997) investigated how general chemistry laboratory was taught and managed and what varieties of practices including assessment were being used in randomly selected 203 U.S. colleges and universities with chemistry programs approved by the American Chemical Society. The findings of this study indicated that seventy-four percent of institutions schedule laboratory for 3 hours per week and the laboratory directions used in general chemistry are predominantly unpublished, internally produced manuals (60%); commercial manuals (29%) or separates (11%) are also used. Ninety-one percent of respondents said their students often or almost always follow step-by-step instructions from the laboratory guide. Eighty percent expressed that their students seldom or never are allowed to go beyond regular laboratory exercises and do investigations on their own. Sixty-eight percent said their students seldom or never are asked to design their own investigations. Seventy-nine percent said their students seldom or never identify the problems to be investigated (Abraham et al., 1997, pp. 591-593). In terms of assessment in the general chemistry laboratory, the results of this study showed that laboratory reports in most institutions are the major contributor to the laboratory grade. Laboratory quizzes or exams focusing on knowledge about concepts or principles in 89% of those institutions are other important source for the laboratory grade. For example, seventy-one percent also use pre-laboratory quizzes to account of the laboratory grade. (Abraham et al., 1997, p. 593). These results indicated that verification or traditional laboratory instruction and traditional assessment practices have been used in most of general chemistry laboratories in U.S. colleges and universities. Overall, this study revealed that both teaching and assessment approaches in general chemistry laboratories have very similar characteristics for both contemporary countries such as the United States and developing countries such as Turkey. It may be hypothesized that university students may not improve their attitudes toward chemistry laboratory work as a result of the laboratory learning environment described above.

Meaningful Learning in Chemistry

In order to increase students' attitudes toward chemistry laboratory, students' learning and experience taking place in university chemistry laboratory first should be meaningful for them. In other words, if students think that they understand chemical concepts better through their chemistry laboratory investigations, and the knowledge they learned is more permanent, they can improve their attitudes toward chemistry laboratory work, including their career planning, perception of the value of laboratory work, and enjoyment of performing laboratory investigations (Kaya & Ebenezer, 2003).

For meaningful learning in chemistry laboratory education, the construction of new knowledge begins with observations of events or objects through the concepts, describing regularity in events (anything that can be made to happen) or objects (anything that exists and can be observed) (Novak & Gowin, 1984). Because our purpose was to help students understand concepts and make important conceptual connections in chemistry experiments, we attempted to increase meaningful learning in laboratory and attitudes toward chemistry laboratory.

"Progressive differentiation" and "integrative reconciliation" are two major principles of meaningful leaning in chemistry laboratory. Progressive differentiation is the progression of concepts in the student's mental structure. The concepts become reorganized, elaborated, more precise, and both more inclusive and more exclusive (Novak & Gowin, 1984; p.97). For example, the reaction rate should be related to the concentration of reactant and these central concepts should be connected with other key concepts such as, collision of particles, activation energy (as internal), volume and pressure (as external). Integrative reconciliation of concepts has occurred when two or more concepts are seen to relate to each other in a new manner to describe a new perceived regularity (Novak & Gowin, 1984; p.97). According to this description, for example, reaction rate and chemical equilibrium are not isolated concepts. These key concepts are related to sub-concepts (i.e., dissociation of a weak acid, dissociation constant) and must be seen in a new perceived regularity (i.e., in equilibrium of a weak acid). The principle of integrative reconciliation is really important in the learning of chemistry because chemistry is a discipline where the concepts are interrelated with each other. Novak and Gowin (1984) claim concept mapping is a visual tool that can illustrate how progressive differentiation and integrative reconciliation might take place in the cognitive structure of a student.

For meaningful learning to occur, concept maps may be used to explore and graphically represent students' understandings of concepts and relationships between or among concepts of a particular topic in science (Ebenezer & Haggerty, 1999). The teacher observes students' external representation of personal thinking and makes attempts to make sense of the content and structure of a student's knowledge frameworks how the student perceives the concepts, how the student sets up the relationships between concepts, and what examples the student gives to support his/her understanding of concepts (Cho, Kahle, & Nordland, 1985). Assessment of such knowledge frameworks reveals students' conceptions of a particular object or event. Thus concept map is a powerful tool for identifying alternative conceptions that consists of complex propositional framework. For example, Pendley, Bretz, & Novak (1994) revealed incorrect understanding of university students in chemistry through concept maps although these students had scored very high on written examinations. For more studies that have used concept maps to reveal alternative conceptions refer to Wandersee, Mintzes, and Novak (1994).

Students' conceptions may be the starting point for laboratory experiment, interpretive discussions, argumentation, and negotiation (Ebenezer & Fraser, 2001). Roth and

Roychoudhury (1993) facilitated meaningful learning in a science laboratory by engaging small groups of students to collaboratively construct concept maps to help change their conceptual understanding. This process of teaching involves the teacher acting as discussant to mediate learning. For evaluating students' conceptual understanding and track his/her conceptual growth that would reflect progressive differentiation and integrative reconciliation of knowledge, a portfolio of student concept maps is useful (Nakhleh, 1994). Concept maps not only serve as a meaningful learning tool in science that requires the student to reorganize, restructure or replace existing conceptions for accommodating new ideas (Smith, Blakeslee, & Anderson 1993), but also an assessment tool to examine the content and structural knowledge (Liu & Hinchey, 1996; Markham, Mintzes, & Jones, 1994). Accordingly, argumentative discourse activities founded on concept mapping may affect students' attitudes toward chemistry laboratory in a positive direction.

Domin (1999a) states in his study named "a review of laboratory instruction style" that research is needed that addresses which style of laboratory instruction best promotes the following specific learning outcomes: (1) conceptual understanding, (2) retention of content knowledge, (3) scientific reasoning skills, (4) higher-order cognition, (5) laboratory manipulative skills, (6) better attitude towards science, and (7) a better understanding of the nature of science. Science laboratories should help students in constructing and/or reconstructing their conceptual framework and constructing new knowledge form the experiences in the laboratory that they consciously integrated to their prior knowledge (Roth & Rochoudhury, 1993). In this connection, the aim of this study is to explore if scientific discussions based on student-constructed pre- and post-laboratory concept maps significantly improve university students' attitudes toward chemistry laboratory compared to traditional laboratory teaching.

Methods

Participants

A total of 91 students, ages 18 and 19, were randomly selected from eleven university general chemistry laboratory classes taught in the Faculty of Education, Gazi University, Ankara, Turkey. Forty-five students were in the experimental group, and 46 students were in the control group.

Procedures

This study involved pre-test post-test control group design (Campbell & Stanley, 1963). After the pre-tests were administered to both groups, the laboratory course in the experimental group began with three training sessions on concept mapping, which involved teaching students how to construct concept maps using several chemical topics.

Prospective Science Teachers' Training and Practice in Concept Mapping

"After students learn how to construct concept maps, their maps can serve as powerful evaluation tools," states Novak and Gowin (1984, p. 23). Hence, the first semester of this course was spent to enable the PSTs to learn and intensively practice how to construct concept maps involving in the general chemistry laboratory investigations before using their concept maps as an assessment tool. The laboratory course in the first semester began with three training sessions (5 hours long) on concept mapping, which involved teaching PSTs how to construct concept map using several chemical topics. The first training session consisted of explaining and discussing what was meant by a concept and the associated terminologies. In the second training session, a concept map was collaboratively constructed with the PSTs on the topic of particulate nature of matter. Hierarchical and nonhierarchical concept maps were shown. As homework assignment, the PSTs individually prepared and submitted a concept map of a chemistry topic of their own choosing before the third session. At the beginning of the third session, the PSTs were given feedback based on their concept maps with respect to the organization of concept maps, selection of appropriate linking words, and the distinction between the cross-link and proposition. After these training sessions, they began constructing pre- and post-laboratory concept maps for each chemistry laboratory investigation and had a huge experience on constructing the concept maps for their chemistry laboratory investigations.

The students were grouped into small groups to facilitate collaborative learning, which would allow students to make decisions by consensus and to seek assistance primarily from their peers. During the next five laboratory sessions (*argumentation)*, including individual, small and large group discussions, based on students' pre- and post-lab concept maps about chemical concepts involved in general chemistry laboratory experiments were carried out with students.

Instrument

A questionnaire of attitudes toward chemistry laboratory (QATCL) developed by the researchers consisted of a 40 positive and negative item-Likert Scale, with 'strongly agree', 'agree', 'undecided', 'disagree' and 'strongly disagree'. Scores of 5, 4, 3, 2 and 1 respectively were assigned for positive items, and reverse scoring for negative items. QATCL consisted of six factors: Special interest to chemistry laboratory (10 items), chemistry lab as a difficult subject (5 items), chemistry laboratory in school science (6 items), anxiety toward chemistry laboratory (7 items), career planning related to chemistry laboratory (5 items), and perception of chemistry laboratory as an important subject (7 items). Alpha-reliability coefficient of QATCL was found to be 0.83 for this study.

Data Analysis

A one-way between groups analysis of covariance (ANCOVA) was used to analyze whether or not there are significant differences between the control and the experimental groups on the posttest scores of QATCL. In the beginning of the study, students' pre-test scores of QATCL were used as the covariates for controlling pre-existing differences between the experimental and control groups.

Program Development and Context

The conceptualization of science learning as argument has been recently proposed by Driver, Newton, and Osborne (2000), Kuhn (1993), Jimenez-Aleixandre, Bugallo-Rodriguez, and Duschl (2000). According to Driver et al,. (2000), scientific discussions or arguments are seen to be at the heart of science and central to the discourse of scientists and if science education is to help students engage with the claims produced by science-in-the-making, science education must give access to these forms of arguments through promoting appropriate classroom activities (p. 288). During this research study, we used students' pre- and post-lab concept maps as a tool to carry out the scientific argumentation, including individual, small and large group discussions, about chemical concepts involved in general chemistry laboratory experiments between us and students, and among students.

Laboratory Design

First, the instructor and two research assistants spent 5–10 minutes with each student to discuss his or her pre-lab concept map. The purpose of the individual discussion was to understand students' reasons for their conceptions and help students become aware of their own preconceptions. During the individual discussions, we focused more on students' partial understanding, alternative conceptions, and also critical propositions. We asked students to answer our questions based on their pre-laboratory concept maps and to put forward their reasons for their responses. For example, the following dialogue between the instructor and the student based on his pre-lab concept map (see Figure 1) of chemical equilibrium gives a glimpse of the nature of the individual discussion. (Note: This individual discussion was carried out in Turkish).

After the individual discussions in each small group, we carried out a small group discussion (10 minutes) with all members of each small group. Each student of small groups was asked to listen carefully his or her peers during individual discussions. So, students were asked to evaluate each other's arguments during the small group discussions. When they agreed, they were encouraged to say their reasons, or when they disagreed, they were encouraged to challenge with counterarguments. Instructor did not intervene to students' responses and did not provide any feedback. It should be noted that we always avoided explicit evaluation of students' answers such as "right" or "wrong".

Afterwards, students were engaged in a *large group discussion* to negotiate scientific meanings based on our findings in pre-lab concept maps and the individual and small group discussions. For example, students' pre-lab concept maps, individual and small group discussions revealed that the chemical equilibrium is not a dynamic process. Hence, the instructor built a large group discussion focusing on the differences between static and dynamic equilibrium using two every day examples: (a) static equilibrium: children on a see-saw at the balance point (i.e., the equilibrium position) no movement of the children or the see-saw occurs; (b) dynamic equilibrium: a boy ascending the escalator at the same rate as the escalator descends. At the balance point (i.e., the equilibrium position) the boy and escalator are moving at the same rate in opposite directions.

Students collected records of their lab investigations, transformed these data into graphs, tables, figures, and schemas, interpreted their records and transformations, and made knowledge claims. Students were asked to examine their own preconceptions in pre-lab concept maps with the findings of their lab investigations. Subsequently, a large group post-lab interpretive discussion was carried out. Students' scientific comments concerning the lab investigations were recorded on the board and interpreted to determine whether or not students answered their initial questions. For example, students were asked "how can you explain the precipitation of $BaCrO_{4(s)}$ by adding $NaOH_{(aq)}$? They said, "color change by adding $NaOH_{(aq)}$ in the system indicated that the reaction B shifted toward reactant and this effect increased the concentration of CrO_4^{-2} in the reaction B. Simultaneously, because of the CrO_4^{-2} is common ion effect in the reactions A and B, an increase of CrO_4^{-2} affected the reaction A. And reaction A shifted toward product, namely precipitating $BaCrO_{4(s)}$." And also they were asked "How did they understand that the cobalt complex equilibrium is an exothermic reaction?" They answered, "decreasing the temperature by putting the reaction beaker under the cold water shifted the equilibrium toward the product side (pink). According to Le Chatelier's principle, decreasing the temperature of a system at the equilibrium shifts the position of equilibrium toward the product side in only exothermic reactions."

The instructor also carried out post-lab discussions to provide sub-microscopic explanations to their macroscopic observations in the foregoing chemical equilibrium reactions. For example, although our students had experienced the application of Le Chatelier's principle--the effects of concentration and temperature changes on the chemical equilibrium—in their lab investigations, they could not explain the changes in the rates of forward and reverse reactions during the restoration of chemical equilibrium. Hence, the instructor directed the students to think about the sub-microscopic properties of the chemical equilibrium reactions**.** Similarly, interpretive discussions with respect to the non-observable properties were carried out in all other lab investigations.

After post-lab discussions, students individually prepared post-lab concept maps by using their own concept labels. The purpose of the post-lab concept maps was especially to help students become aware of the conceptual changes. The changes in their conceptual knowledge based on their post lab concept maps (see Figure 2), including their new alternative conceptions and partial understandings were discussed.

For example, students understood that when equilibrium is re-established after temperature or concentration changes, the rates of forward and reverse reactions are equal to those at the initial equilibrium, and an increase in concentrations of products is directly proportional to the value of Keq, which led to the discussion of dynamic structure of chemical equilibrium on mathematical equation ($K= [C]^c [D]^d / [A]^a [B]^b$).

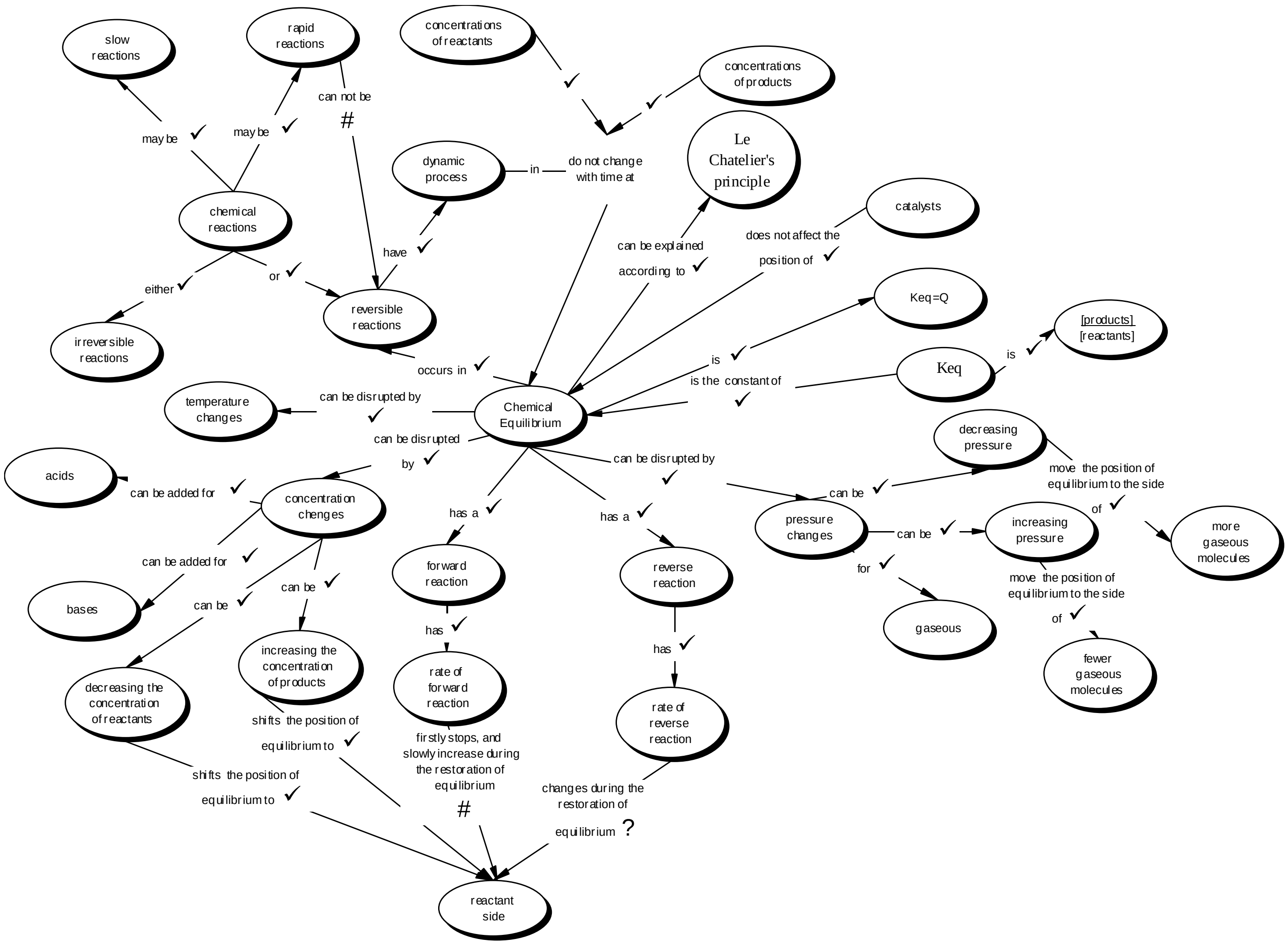

Figure 1. A student's pre-lab concept map for the chemical equilibrium.

Instructor: if you add a small amount of salt to water in the glass, what happens?

Student: It will dissolve until there is no salt left.

Instructor: Can you explain it using a relevant chemical equation?

Student: $NaCl_{(s)}$ ==> $Na^{+}_{(aq)}$ + $Cl^{-}_{(aq)}$ The solid NaCl dissolves Na^{+} and Cl^{-} ions are in water.

Instructor: Okay, if you keep adding salt, what do you think happens?

Student: There is a limit to its solubility, and eventually solid will stay at the bottom of the glass.

Instructor: After the solid settles at the bottom of the glass, what do you think about all species in the glass?

Student: I cannot understand exactly.

Instructor: In other words, what is the relationship between Na^{+} and Cl^{-} ions and solid NaCl at the bottom?

Student: The solid at the bottom can dissolve forming Na^{+} and Cl^{-} ions, and Na^{+} and Cl^{-} ions can form the solid at the bottom. There are two reactions.

Instructor: Can you explain more?

Student: (student writes the equation) $NaCl_{(s)}$ <==> $Na^{+}_{(aq)}$ + $Cl^{-}_{(aq)}$ at the same time, there is dissolving and precipitating.

Instructor: You used the double arrow in the chemical equation this time. Why?

Student: Yes the double arrow indicates that when the salt is dissolved, the Na^{+} and Cl^{-} ions are resolidifying at the same rate. The system is at the equilibrium between the dissolving and precipitation.

Instructor: What do you mean by "the same rates"?

Student: I think that this system has two reactions, and normally two reaction rates. At the equilibrium position, forward reaction rate is the same as the rate of reverse reaction.

Instructor: Can you affect this equilibrium position between dissolving and precipitation?

Student: Yes, I can add $HCl_{(aq)}$or $NaNO_{3(aq)}$ to the solution for shifting the equilibrium toward the forward reaction. Because if I add $HCl_{(aq)}$, the equilibrium shifts toward the NaCl solid because of the increase in Cl^{-} ions in the solutions. Also if I add $NaNO_{3(aq)}$, the equilibrium shifts toward the NaCl solid because of the increase in Na^{+}

ions in the solutions. But when I add these solutions, the rates of forward and reverse reactions change compared to their rates at the equilibrium.

Instructor: Can you explain your idea? How and why do these rates change?

Student: When I add one of them, the rate of forward reaction will stop for only one second, while the reverse reaction rate will be very fast because the rate of reverse reaction increases because of the increase in Na^+ or Cl^- ions in the solution. But, in the course of time, the rate of forward reaction is getting faster, and also the reverse reaction rate will be getting slower. But, I know that these ideas are not correct because I observed my pre-lab concept map and also I should correct my other link related to the concept of rate of forward reaction because the rate of reverse reaction should increase during the restoration of equilibrium by shifting the position of equilibrium to the reaction rate. Finally forward reaction rate will be the same as the rate of reverse reaction at the initial equilibrium. And so the same equilibrium will occur.

Instructor: How can you affect this equilibrium position toward dissolving or Na^+ and Cl^- ions?

Student: This time I can add more solid NaCl in water for shifting the equilibrium toward the ions. But, when I add the solid, the rate of forward reaction increases because of adding solid NaCl, while the rate of reverse reaction decreases.

Instructor: Also, you constructed a relationship between the concepts of rapid reaction and reversible reactions “rapid reactions can not be reversible reactions” in your pre-lab concept map. Can you explain your idea in more detail?

Student: Chemical reactions are either rapid or slow. Rapid reactions go to completion and cannot be reversible reactions. For example, the reaction “$Mg_{(s)}$ + $HCl_{(aq}$ ==> $H_{2(g)}$ + $MgCl_{(aq)}$” is very fast, and does not have an equilibrium.

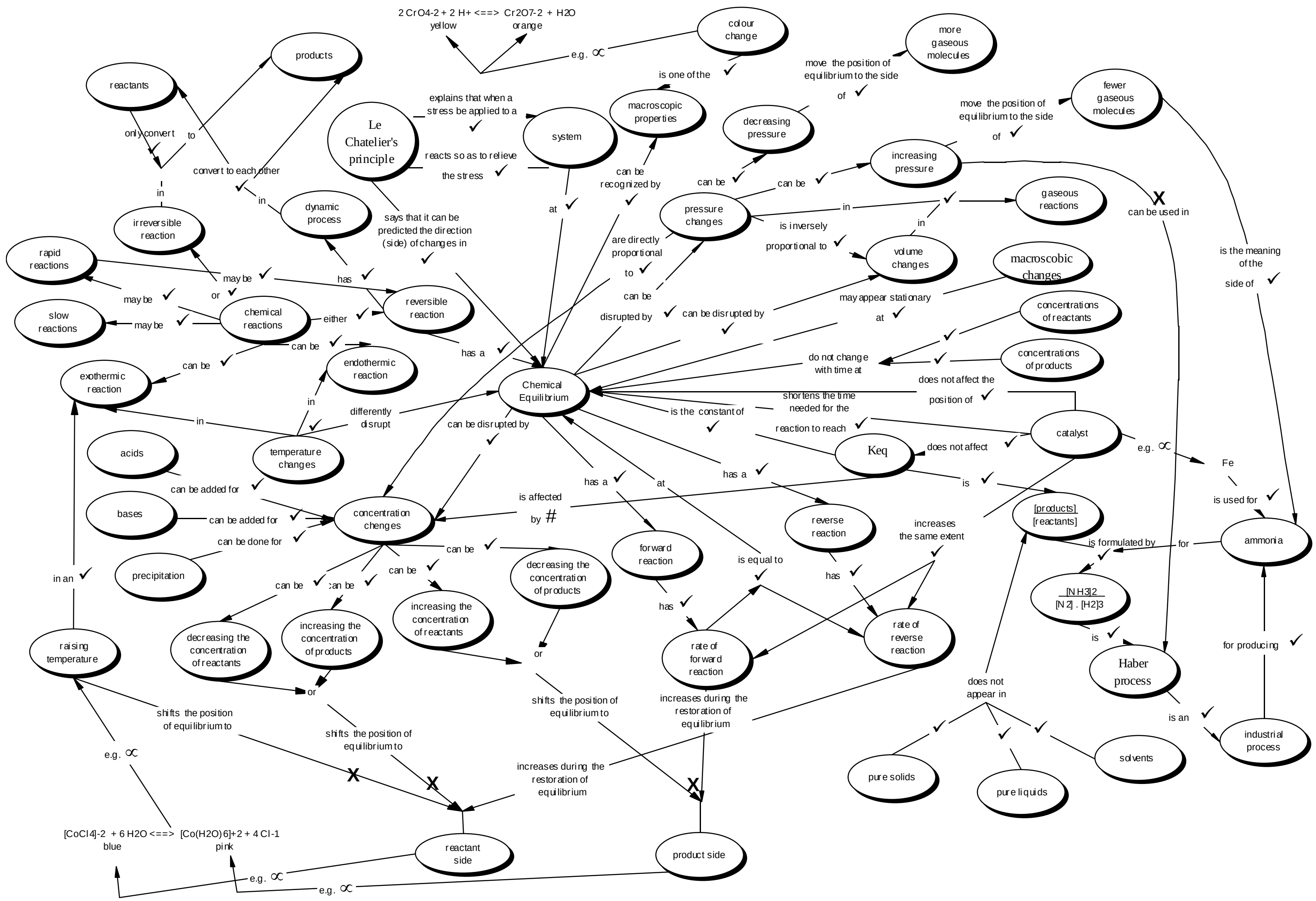

Figure 2. The same student’s post-lab concept map for the chemical equilibrium

Results

Mean scores of students' pre-tests on the QATCL in the control group is higher than those in the experimental group are shown in Table 1.

Table 1. Means and standard deviations (below) of the experimental and control groups for pre-tests of the QATCL as used the covariates.

Test	Control Group (N = 46)	Experimental Group (N = 45)
	137.70	134.36
QATCL	18.40	17.45

Results of ANCOVA on the post-test scores of QATCL indicated that there is a significant difference, $F = (1, 88) = 29.82$, $p < 0.001$, between the experimental and control groups. The adjusted mean scores of the QATCL post-test in Table 2 indicate that the control group had an adjusted mean of 158.34 on the QATCL post-test, while experimental group had an adjusted mean of 174.37 on the QATCL post-test. These results show that students taught with scientific argumentation founded on student-constructed pre- and post-laboratory concept maps significantly developed more positive attitudes toward chemistry laboratory than those in the control group, who learned chemistry laboratory with the traditional way.

Table 2. Unadjusted mean scores, standard deviations, and adjusted mean scores of the QATCL post-test for two groups

Groups	N	Unadjusted mean	SD	Adjusted mean
Control Group	46	163.29	17.31	158.34
Experimental Group	45	171.18	18.15	174.37

Discussion

In science education literature, there have been no studies focusing on how to engage prospective teachers in argumentative discourse involving the laboratory investigations although argumentation as a teaching approach for science education has been proposed by many science educators. Previous studies have focused more on developing and assessing students' arguments in high or middle school science classrooms, using Toulmin's argumentation pattern (e.g., Erduran et al., 2004; Osborne et al., 2004; Jiménez-Aleixandre et al., 2000). This study explored the effectiveness of scientific argumentation founded on student-constructed pre- and post-laboratory concept maps on students' attitudes toward chemistry laboratory in a university general chemistry. The quantitative results of data in this study confirm a significant improvement favoring the experimental group. Accordingly, this study first is a contribution to the literature indicating argumentative discourse activities that consist of small-group and whole-class discussions in pre- and post-laboratory sessions improve students' attitudes toward chemistry laboratory.

We also found that students who learn by using scientific argumentation founded on their concept maps felt more competent and confident as well as enjoyed the challenge of constructing new ideas with each other or us during scientific discussions. Also, students who understood their weaknesses during individual and small group discussions struggled to promote their conceptual understanding in the relevant concepts, and students often talked about the development of their argumentative abilities involving chemical topics. Moreover, our unstructured interviews with students about scientific argumentation based on their concept maps showed that their argumentation made the knowledge they gained in chemistry laboratory course more permanent. This kind of laboratory style with scientific argumentation gave opportunities for students to engage in their own learning in chemistry laboratory and so, gave them a sense of ownership over their laboratory investigations. Another important reason for improved attitudes toward chemistry laboratory was because students were provided greater autonomy to take control of their own learning through scientific argumentation. So, we attribute their positive feelings toward chemistry laboratory to the scientific argumentation based on their concept maps.

Overall the present study demonstrates that Turkish PSTs can successfully perform the argumentative discourse activities using their concept maps when they have enough knowledge and experience on this new laboratory learning environment. Accordingly, the results of this study primarily imply that the PSTs should be provided with frequent opportunities to discuss their ideas in small-group and whole class settings to increase their attitudes toward chemistry laboratory. Subsequently, we should expect teacher candidates to effectively use argumentative discourse to improve their own students' attitudes toward science and laboratory in their future classrooms. Future research should focus on how PSTs transform their knowledge and experiences with the argumentative discourse founded on concept mapping into K-12 settings.

References

Abraham, M. R., Cracolice, M. S., Graves, A. P., Aladamash, A. H., Kihega, J. G., Palma Gil, J. G., & Varghese, V. (1997). The nature and state of general chemistry laboratory courses offered by colleges and universities in the United States. *Journal of Chemical Education, 74*, 591-594

Birenbaum, M. (2003). New insights into learning and teaching and their implications for assessment. In M. Segers, F., Dochy & E. Cascallar (Eds.), *Optimising new models of assessment: In search of qualities and standards* (pp. 13-36). Dordrecht: Kluwer Academic Publishers.

Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental designs for research*. Boston: Houghton Mifflin.

Cho, H., Kahle, J.B., & Nordland, F.H. (1985). An experiment of misconceptions and difficulties in genetics and some suggestions for teaching genetics. Science Education, 69, 707-719

Domin, D. S. (1999a). A content analysis of general chemistry laboratory manuals for evidence of higher order cognitive tasks. *Journal of Chemical Education, 76*, 109-111.

Domin, D. S. (1999b). A review of laboratory instruction styles. *Journal of Chemical Education, 76*, 543-547.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education. 84*(3), 287-312.

Ebenezer, J.V., & Fraser, D. (2001). Chemical engineering students' conceptions of energy in solution process: Phenomenographic categories for common knowledge construction. Science Education, 85, 509-535.

Ebenezer, J.V., & Haggerty, M.S. (1999). Becoming a secondary school science teacher, Merill Press, New Jersey.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the use of Toulmin's Argument Pattern in studying science discourse. *Science Education*, 88(6), 915-933

Jiménez-Aleixandre, M. P., Rodríguez, A. B., & Duschl, R. A. (2000). “Doing the lesson” or “doing science”: argument in high school genetics. *Science Education, 84(6)*, 757-792.

Kaya, O. N. & Ebenezer, J. (2003, March). A Longitudinal Study of the Effects of Concept Mapping and Vee Diagramming on Senior University Students' Achievement, Attitudes and Perceptions in the Science Laboratory. Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST), Philadelphia, PA.

Kuhn, D. (1993) Science as argument: Implications for teaching and learning scientific thinking. *Science Education*, *77*(3), 319-338.

Liu, X., & Hinchey, M. (1996). The internal consistency of a concept mapping scoring scheme and its effect on prediction validity. International Journal of Science Education, 18, 921-397.

Markham, K., Mintzes, J., & Jones, M.G. (1994). The concept maps as a research and evaluation tool: Further evidence of validity. Journal of Research in Science Teaching, 31, 91-101.

Nakhleh, M.B. (1994). Chemical education research in the laboratory environment. How can research uncover what students are learning? Journal of Chemical Education, 71, 201-205.

Novak, J.D., & Gowin, D.B. (1984). Learning how to learn, Cambridge, England: Cambridge University Press.

Osborne, J.F., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in science classrooms. *Journal of Research in Science Teaching*, *41*(10), 994-1020.

Pendley, B., Bretz, R.L., & Novak, J.D. (1994). Concept maps as a tool to assess instruction in chemistry. Journal of Chemical Education, 70, 9-15.

Roth, W-M., & Roychoudhury, A. (1993). Using Vee and concept maps in collaborative settings: Elementary education majors construct meaning in physical science courses. School Science and Mathematics, 93, 237-243.

Smith, E.L., Blakeslee, T.D., & Anderson, C.W. (1993). Teaching strategies associated with conceptual change learning in science. Journal of Research in Science Teaching, 32, 521-534.

Wandersee, J.H., Mintzes, J.J., & Novak, J.D. (1994). Research on alternative conceptions in science, In: D. Gabel, (Ed.). Handbook of Research on Science Teaching and Learning, New York: Macmillan.