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Scientific Inquiry Based Professional Development Models in Teacher Education

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Abstract

Scientific inquiry helps students develop critical thinking abilities and enables students to think and construct knowledge like a scientist. The study describes a method course implementation at a major public teachers college in Turkey. The main goal of the course was to improve research and teaching abilities of prospective physics teachers (N=48) by developing scientific inquiry skills. The impact of the course was measured in two-folds: (a) The results obtained from pre- and post-course scientific inquiry self-evaluations of student teachers, which showed a statistically significant improvement, (b) independently measured scientific inquiry levels, which were found highly correlated with student grades from practical courses. Qualitative data indicated that the student teachers were having difficulties in applying mathematical formula into physics applications.

Key Words

Professional Development Models, Physics Education, Teacher Education, Action Research, and Scientific Inquiry.

Scientific inquiry based classroom activities help students develop critical thinking skills and enable them to construct knowledge like a scientist (Schneider, Krajcik, Marx, & Soloway, 2002). A strong foundational understanding of scientific inquiry has positive effects on both student achievement and attitudes towards mathematics and science (Anderson, 2002). Therefore, scientific inquiry is widely accepted as an effective instructional practice to teach science in today's classrooms and teachers need to excel in guiding their students to construct knowledge like scientists (National Research Council, 1996, 2000).

The success of professional development of student teachers depends on the balance between theoretical and practical teaching applications offered in teacher education programs (National Science Teachers Association [NSTA], 1990, 2004, 2006). To achieve this balance, two common learning strategies are used to develop teaching abilities: *action research* and *learning cycle*. The student teachers use action research approach to improve their teaching in the classroom, whereas learning cycle helps them utilize teaching knowledge in the mental domain and helps student teachers understand the science concepts in depth by authentic hands-on activities (Elliot, 1993; Hopkins, 1993; Lawson, 1995; Stenhouse, 1975). Both strategies are at the core of the models developed in this study and they guide the implementation of the methods course.

Thus, the main problem of the study was to describe the methods course in a physics teacher education program at a Turkish university and to determine its effectiveness in terms of student teachers' self-evaluations of their teaching and independent assessment of their scientific inquiry levels. Specifically, the study investigated whether scientific inquiry levels of the participants were statistically significantly regressed by their grades in theoretical and practical teacher education courses.

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Theoretical Framework

Scientific Inquiry and Inquiry Oriented Learning: Scientific inquiry develops students' abilities to question the researchable events of the nature in a critical way. As students learn the concepts and the scientific processes, they develop skills on approaching phenomena like a scientist (National Research Council, 1996). The scientific inquiry helps students explore the unexplored knowledge by improving their critical thinking skills in authentic contexts (Roth & Roychoudhury, 1993). The proposition that links learning concepts and scientific inquiry is backed up by empirical research results, which indicated practically significant improvements in student achievement scores in multiple academic disciplines, including physics and mathematics (Anderson, 2002; Çorlu & Corlu, 2007; Lawson, 1995; National Research Council, 2000).

Action Research for Improving Teaching Skills and Strategies: Action research is an educational research strategy that was developed during the *teacher as a researcher* movement (Stenhouse, 1975). Scientific inquiry aims to democratize the educational research by actively including teachers in the inquiry process (Stenhouse, 1985). The first order action research, according to Elliot (1993), is the study of a social situation with a view of improving the quality of professional action within it, while the objective of the second order action research encompasses educational research.

Action research approach is based on observation and action research intends to find out the proper actions to improve teaching skills (Çorlu, 2005). Action research does not only provide scientific evidence to such actions that may improve teaching skills but it also generates important practitioner-relevant information (Çorlu, Niğdelioğlu, & Kaymak, 2008). Action research is particularly important in creating the 21st century workforce by well-educated teachers, given the results of a recent international comparison study that low teacher quality is a major problem in many developed countries (Organisation for Economic Cooperation and Development [OECD], 2009).

Professional Development Models: Learning Cycle for Inquiry Concept (LCIC) and Learning Cycle for Conceptual Inquiry (LCCI)

The importance of scientific inquiry for teacher education, thus for the professional actions of teachers, is well supported in the literature (National Research Council, 1996, 2000). The importance of action research for the professional development purposes is also clearly established (Brydon-Miller, Greenwood, & Maguire, 2003). Under the guidance of previously documented links between professional development, scientific inquiry, and action research, two related models are developed in this paper. However, the main objectives of the models were different from one another. LCIC focused on improving the inquiry concepts and related skills through action research, which is identified as a descriptive learning cycle. The latter, LCCI, however, focused on improving the conceptual high-level learning through inquiry approaches based on action research.

The common phases of LCIC and LCCI can be summarized as follows: (*i*) Planning of inquiry concepts and skills/conceptual understanding, (*ii*) learning, developing and investigating actions that improve inquiry concepts and skills/conceptual understanding, (*iii*) evaluating and creating a new plan (if necessary) for deeper understanding of inquiry concepts/conceptual understanding. Through the common phases of LCIC and LCCI, certain competencies are anticipated to develop, such as; (*i*) conceptual inquiry skills (identifying the problem-analyzing-setting hypotheses-generating a synthesis-problem solving and developing a course/experiment), (*ii*) critical thinking skills, (*iii*) conceptual high level learning of the content knowledge.

Method

Participants

Participants (N=48, 24 females) were fifth-year physics teacher candidates (student teachers). Sample was drawn with a convenient sampling method from a highly popular (in terms of students' university admittance scores) public teacher's college in Istanbul, Turkey. Student teachers were considered at postgraduate level. They had completed their area-specialised courses (physics and other content courses) before taking the methods course.

Data Collection and Analysis

In the first teaching phase of the course (experimental investigation assignment #1), data were collected using tools which were teaching skills evaluation form, digital video recording, and learning gains evaluation forms. After the first teaching phase, the collected data were analysed by the student teachers and discussed with the student teachers. In the second phase, (experimental investigation assignment #2) student teachers were expected to further develop the teaching and research quality of their designs and improve their teaching practices. After the completion of both phases, learning gains in terms of the difference between pre- and post test results and scientific inquiry skills at the end of the course were expected to improve.

Student teachers assessed their own learning gains in experimental design and investigation projects by using the survey adapted from Doran, Chan, Tamir, and Lenhardt, (2002, p. 63). The adaptation included 24 items with 1-5 Likert scales and it was implemented as pre- and post-tests. In addition, items from Lawson (1995) and Flick and Tomlinson (2006) surveys were compiled to create the scientific inquiry survey, which included 25 items with 0-4 Likert scales. Scientific inquiry survey was implemented as a post-course survey and collected data were used to investigate statistical significance of the correlations with student teachers' grades in their subject courses, such as practical courses (methods course and physics laboratory), theoretical courses (physics and mathematics), and their overall GPA.

Qualitative data were composed of the methods course instructor's observations based on in-class interactions and video recordings, in addition to artefacts, such as course related materials, worksheets, lab reports, lesson plans, and experiment instructions. A member check procedure (Lincoln & Guba, 1985) was implemented at the end of the course with the student teachers by sharing and discussing course instructor's reports that included the narrative of instructor's observations.

The tools used to collect data as parts of the method course activities are listed as follows: (*i*) Inquiry-oriented learning files/portfolios of student teachers, which included several educational materials (including lesson plans, worksheets, reports and evaluation of the experimental data), which were designed by the student teachers, (*ii*) recorded videos during student teachers' microteaching and experimental designs, (*iii*) course instructor's evaluation notes focusing on inquiry-oriented learning processes, (*iv*) self- and peer evaluations of a member of the working teams (and of external teaching assistant), who recorded their observations according to the instructional questioning analysis form designed according to Bloom's Taxonomy (1995), (*v*) end of the course scientific inquiry test, (*vi*) self assessment of inquiry-oriented experimental design and instruction (with learning gains survey), and (*vii*) self assessment of the research projects (with learning gains survey).

Results

The Implementation of the Methods Course

Experimental Design: Each group of student teachers had to plan, prepare, and present an experimental design. Groups recorded their observations in explanatory narratives during their work and as they watched their microteaching on the video recordings. They completed the given surveys, during and after their first experimental designs. The second experimental design was the assignment in which the teams were expected to reflect on their professional development through the results obtained from their action research activities and the feedback given by the course instructor. Lastly, teacher candidates were challenged with an extra investigation project, through which a third experimental design was assigned to the teams and they were expected to compete against each other.

During the experimental design and investigation projects, teams consisting of three or four student teachers, worked independently in order to show their ability in the form of a genuine and original output. As a result, student teachers developed their own laboratory instruments, designed their experiments, tested their learning gains, and evaluated their teaching. Two examples will be presented in this paper to display how the course instructor applied the proposed LCIC and LCCI models to facilitate the experimental designs. The course instructor assumed that the student teachers were not familiar with the theoretical formula for the assigned problems (otherwise, they should have been given another problem they did not know already).

Example for LCIC: The overarching objective of the LCIC model is to help student teachers learn the inquiry concept and to teach it effectively. Thus, the focus is on learning the inquiry process rather than a conceptual understanding of the scientific phenomenon.

Question: What are the possible relationships between the parameters in the pendulum system, and how are they defined?

In order to answer the question (thus to learn to teach through scientific-inquiry based methods), student teachers started to work on their experimental designs as a team. The teamwork included the collaborative work in the experimental design, classroom management, and managing the experiment through inquiry, evaluation and observational research. The materials needed by student teachers, who worked independently in the laboratory, were prepared by themselves with the help of a laboratory technician so that the instructor was able to check the inquiry process in real-time and to evaluate the quality of the designed learning materials (lesson plan, handouts, and worksheets prepared by the student teachers). The course instructor was also responsible of ensuring the lesson and the materials were scientific-inquiry oriented and of providing appropriate feedback, whenever necessary.

The instructor presented additional investigative problems during the experimental design phase: (*i*) The inspection of the scientific method process and the inquiry concepts including identifying the problem, analyzing, hypothesizing, making synthesis and evaluation, (*ii*) how the student teachers are identifying the main investigation problem for the simple pendulum, (*iii*) how they describe the relationship between independent and dependent variable(s) using partial differentiation?

Several other questions were asked to the student teachers: (*i*) If the pendulum's period T is hypothesized at some point to be a function of *l, g, m, orF*, (or any other function), what is the relationship between the variables and how this relationship can be shown experimentally? Given, length: (*l*), gravity: (*g*), mass: (*m*), and angular amplitude: (*F*) in

$$dT = (\partial f/\partial l).dl + (\partial f/\partial g).dg + (\partial f/\partial m).dm + (\partial f/\partial \Phi).d\Phi + \ldots$$

(1)

(*ii*) how can you explain the terms in the main problem with respect to the measured quantities? (Student teachers are required to identify, analyze and solve the problem), (*iii*) how can you create a hypothesis or alternative hypothesis according to the given mathematical equation?, (*iv*) what is the role of the given equation in graphical representation of the problem solution?, (*v*) conduct an error analysis at the evaluation phase of the experiment according to the given equation, (*vi*) how can you show the Eigen frequencies in the pendulum experiments? How can it be taught by a demonstration?

Example for LCCI: Generally, more advanced problems were used in LCCI model to foster in depth conceptual understanding of the problems, rather than focusing on the inquiry process.

Question: What factors affect the inductive resistance of a coil in RLC circuit and how do they change?

In order to answer the question (and to learn to teach in depth conceptual understanding), student teachers started to work on their experimental designs as a team. The team consisted of four student teachers, two of whom were casted in the role of the classroom teacher and the teacher assistant. The role of the third person in the team was to be the observational researcher, while the fourth person was statistically analyzing collected data on team's learning gains. The problem was first analyzed through discussions within the team and sub problems (in the form of different parameters) were created to be assigned to the other student teachers, who were in student role in a physics classroom. The sub problems were supposed to come with some guidelines and instruction. At the end of the teaching period, course instructor expected the leading team to be able to combine the assigned sub problems by discussing and thus, synthesising the graphical representations (i.e., considering integration as the area under the curve) obtained from the sub problems to reach one final equation.

Given, X_L : Inductive resistance; L : Induction coefficient; w : angular frequency; etc.

$$\partial X_L = \partial[f(w, L)] = (\partial f/\partial w).dw + (\partial f/\partial L).dL + \ldots.$$

(2)

Improving In Depth Conceptual Understanding: Following the evaluations of the first team's teaching, the same problem was assigned to a second team. The members of the team were expected to reflect on the findings and teaching of the first team. The objective was to find a better method to improve their friends' conceptual understanding of inductive resistance in RLC circuits. For example, one of the secondary teams tried to change the inductive resistance with various core lengths in the inductive coil, which resulted in a change in the intensity of gloving of the lamp in series RL circuit. The team discussed the possible reasons behind the change in glowing. The second team directed the discussion and the inquiry session in the classroom, so that they could improve their critical thinking and conceptual understanding of RLC circuits. At this point, two photos are presented in *Figures 2,* and *3*, as examples of student teachers' designs.

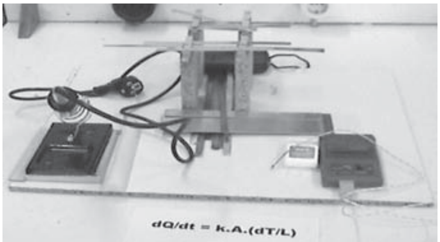

Figure 2.

An Instructional Material Created by Student Teachers as a Part of Their Experimental Design

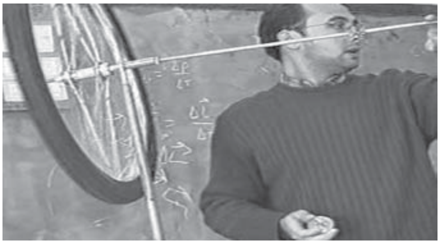

Figure 3.

A Video Snapshot Showing a Student Teacher in Action with His Team's Design.

Action Research as an Integral Component of LCIC and LCCI Models: Action research in the professional development models presented in this paper was carried out periodically in three-steps, which are explained in Table 1. Initially, an additional training was provided on how to effectively use a video camera during in class observations in order to improve student teachers' teaching and observational skills.

Table 1.
Action Research Cycle to Improve Teaching and Scientific Inquiry Skills

Action Research Cycles	Team Work Explanation
1. Preparation cycle	Observation skills are improved
2. Demo recordings	Peer video recordings in the preparation phase.
3. Discussions on the recordings	Sample recordings are discussed, evaluated and last preparations for the actual recording.
1st Cycle	
1. Teaching and observation planning	Planning the development for the action to be observed
2. Peer-teaching/ experiment- video recordings	Observing the application/teaching
3. Discussions on the observation results	If the development is not assessed as satisfactory, planning the second cycle
2nd Cycle and continue developing in three phases.	

New and revised teaching plan of the cycle was based on the evaluation of: (i) Expert, peer, and self-evaluation of teaching/observation, (ii) assessment of learning gain (analysis of the pre- and post test results), (iii) analysis of scientific inquiry test. Other secondary skills concurrently developed through action research cycles can be listed as: (i) Laboratory management skills, (ii) presentation skills, (iii) skills to increase student participation, (iv) time management, (v) safety procedures, (vi) questioning techniques. In short, student teachers observed or were observed during their efforts to improve on the above items during the first experiment phases. After the demonstration of the first experiment, they developed their lesson plans/experiment designs as part of the second cycle, where they suggested and explained the possible alternative methods to improve the design according to the evaluation results.

Summary

The LCIC model aims to provide opportunities to student teachers to develop and improve their scientific inquiry skills, while LCCI model focuses on high level, in depth, and conceptual understanding by improving critical thinking skills. The main role of the action research activities in the proposed models is to construct and improve student teachers' teaching skills and strategies, and they are considered as integral parts of both LCIC and LCCI models.

Quantitative Findings

Student teachers' self-assessments, which were conducted at the beginning and end of the course, reflected how they perceived their self-development in experimental design and projects. The learning gains survey was consisted of 24 Likert type items with five scales and adapted from the work of Doran et al. (2002). The numerical results were summarised in Table 2 and Table 3 where it was shown that we found a strong practical significance between the pre- and post course differences compared to expected effect sizes in educational research.

Table 2.
Self-evaluation of Learning Gains in Experimental Design

Pre-test ± SD	Post-test ± SD	Gain (Effect size)
78.25 ± 13.7	105.25 ± 14.78	Cohen's d= 1.9 ($p < .001$)
Score Reliability Cronbach's α = 0.84	Score Reliability Cronbach's α = 0.82	Pearson's r Correlation Coeff. r = .69 ($p< .001$)

Table 3.
Self-evaluation of Learning Gains in Investigation Projects

Pre-test ± SD	Post-test ± SD	Gain (Effect size
71.96 ± 17.18	103.25 ± 13.8	Cohen's d= 2.0 ($p < .001$)
Score Reliability Cronbach's α = 0.84	Score Reliability Cronbach's α = 0.85	Pearson's r Correlation Coeff. r = .71 ($p < .01$)

Secondly, student teachers were tested independently in terms of their scientific inquiry skills with a second survey (25 items, 0-4 Likert scales, 0-100 range) adapted from Lawson (1995) and Flick and Tomlison (2006). The student teachers' scientific inquiry skill scores were investigated, in terms of their correlations with their average grades in mathematics (mean of four fundamental mathematics courses), physics (mean of four fundamental physics courses); physics laboratory (mean of six laboratory courses) and their grand point averages (GPA). All grades were within the range of 0-100. The correlation coefficients were statistically significant from zero between their scientific inquiry skills scores and their final course grades in the methods course, physics laboratory grades, and their grand point averages (GPA). The highest correlated variable with their scientific inquiry skills was their final grades in the methods course ($r = .584$; $p < .001$). See Table 4.

The data were tested for fit to a linear regression model and to explain the variance in scientific inquiry test scores of the student teachers. The data showed that only the methods course grades were statistically significant at $p = .01$ with a standardized Beta score of .48. The variance explained in our model was estimated to be $R^2 = .46$ and adjusted $R^2 = .35$. The other standardized Beta coefficients of the variables were found as follows: Mathematics (Beta = .17; $p = .37$), physics (Beta = -.43; $p = .06$), physics laboratory (Beta = .31; $p = .24$) and GPA (Beta = .04; $p = .88$).

Thus, the linear regression equation was formed in equation 3 as follows:

$$\text{Scientific\_Inquiry} = .48^{*}\text{Zmethods course}^{*} + .17^{*}\text{Zmatematics} - .43^{*}\text{Zphysics} + .31^{*}\text{Zphysics\_lab.} + .04^{*}\text{ZGPA}. \quad (3)$$

It is noteworthy to emphasize the practical meaning of this equation, which indicates that one standard deviation improvement in student teachers' grades, from the methods course explained in this paper, may indicate a .48 standard deviation increase in their scientific inquiry skills. Remarkable it is also to see the likeliness that the physics course grades (when the lab component is kept constant) does not have a positive effect on scientific inquiry.

Qualitative Findings

One of the themes emerged from the qualitative analysis of the data was student teachers' difficulties, particularly applying mathematical formula into experimental designs. Some student teachers indicated that they were used to think from a single perspective and struggled in creating multiple ideas and solutions. Similarly, course instructor described student teachers to be inefficient in transitioning from theoretical content knowledge

Table 4
Correlation matrix

Mean , SD	Scientific Inquiry	Methods Course	Mathematics	Physics	Physics Laboratory	GPA
Scientific Inquiry (66, 18)	1.00					
Methods Course (72, 9)	.58**	1.00				
Mathematics (58, 6)	.08	.24	1.00			
Physics (56, 4)	.12	.34*	.60**	1.00		
Physics Laboratory (63, 6)	.43*	.56**	.42**	.58**	1.00	
GPA (60, 8)	.40*	.47**	.55**	.73**	.75**	1.00

*Notlar: **. $p < .01$; *. $p < .05$.*

to practical pedagogical content knowledge. It was also found that student teachers believed that applying LCIC and LCCI models would be exhaustive, if the course instructor were alone in the class, and thus, the role of the teaching assistant was critical and necessary. Student teachers, who were in the role of the teacher, also appreciated their peers, who were in the role of a teaching assistant. We observed that the key to the successful implementation of our models was that the course instructor needed to be equipped with a solid content knowledge and pedagogical content knowledge with teaching experience in the high school level. The overwhelming majority of the student teachers indicated that the methods course was harder than what they initially had thought, and that they struggled to succeed at the beginning. However, almost all student teachers indicated they believed they needed such an approach, or showed consent that it was a useful way to learn physics teaching. Another emerged theme was the timing of this methods course. Many of the student teachers believed it would be better to have this methods course during earlier years of their teacher education program.

Discussion

The moderately high correlation (and the highest among others) between the methods course grades and the scientific inquiry test scores, in addition to the variable's statistically significant and relatively high standardized beta coefficient in the linear regression model show that the LCIC and LCCI may be effective pedagogical professional development models. This finding can be explained by the proposition that a good content knowledge in physics and/or mathematics is not enough to implement either LCIC or LCCI models successfully which is supported by previous research findings that indicated that pedagogical content knowledge was a critically important aspect of any scientific inquiry based model in teacher education (Shulman, 1986; Wu & Krajcik, 2006). It would be a significant setback in the quality of instruction at schools, if subject-educated teacher educators did not educate subject teachers. Alternative situations may harm the effectiveness of teacher education programs, particularly in terms of action research opportunities provided to our teachers. We also foresee the necessity of an additional expert teacher or a well-trained student assistant to implement the LCIC and LCCI models successfully in teacher education.

Student teachers had difficulties in transferring their subject content knowledge into the pedagogical field (cf. Capraro, Capraro, Parker, Kulm, & Raulerson, 2005) but also between subjects (cf. Tchudi & Lafer, 1996). This finding can be due to the lack of pedagogical approaches in content courses, such as in physics and mathematics. Lack of correlational relationship between student teachers' grades from these courses and scientific inquiry test may indicate that content courses in physics or mathematics are not helping student teachers learn to think and act like a scientist. Solid mathematics knowledge emerges as a prerequisite to develop scientific inquiry skills in physics (Pratt, 1985). This coincides with the previous research findings that science teaching and mathematics teaching should support each other at school and during teacher education levels (Aydin & Delice, 2007; Corlu, Capraro, & Çorlu, 2011).

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