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A Comprehensive Research Design for Experimental Studies in Science Education

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ABSTRACT. Experimental methods have a discrete place due to their effectiveness to establish cause-effect relationship and, to make manipulations and to provide control over the variables. Although majority of the science education dissertations in Turkey involve experimental studies, lack of sound experimental designs to control validity threats is still an important problem. And also, there is a need to conduct school-wide experiments to test effectiveness of methods and techniques or other reform requirements in science education. These experiments need more comprehensive and powerful research designs to overcome problems about internal validity threats. This study purposes to suggest a new, more comprehensible design of experimental study. Five-group experimental design has been suggesting, by controlling more threats to internal validity, a more sound way to establish cause-effect relationship and to control more variables which are potentially effective on dependent variables of the science education studies.
Keywords: Creative thinking, critical thinking, academic achievement, science process skills

INTRODUCTION

Science and technology are among two most effective areas on human life because of their products' direct effect on various aspects of life. For example, human being experiences reflection of scientific activities including new cure approaches, new nutrition objects (genetically modified plants and animals) to compensate food gap and integration of new facilitative technologies into life. Nonetheless, science and its products also cause to new problems such as global warming, resistant battles to chemicals and nuclear disasters. As a result of its two-sided nature, science provides solution to the problems rooted from products of scientific activities.

In its basic meaning, science is a way of knowing (McComas, 1998, Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). It has advantages over the other types of knowing, which are sensory experience, logic, reaching a consensus with others, learning from authority and making observations (Fraenkel & Wallen, 2006, p.4). Science is based on evidence and observation (Lederman, 2007) and it uses systematic ways called as methods to reach its purposes. Science includes using various methods to explain or describe an unknown thing. These methods can be classified as descriptive method, correlational method, causal-comparative method, one-subject method and experimental method. Experimental method is a quantitative method by which researchers try to determine the impact of an intervention on an outcome for a group in a study (Creswell, 2002). Experimental methods including various experimental designs provide the most sound and strongest way to establish cause-effect relationship and to control external variables effectively (Fraenkel & Wallen, 2006, p.267; Gall, Gall & Borg, 2007, p.379; Shadish, Cook & Campbell, 2002, p.13). The experimental research is also an effective way of eliminating internal validity threats in a study due to its power in controlling external variables and manipulating the focus variables. Internal validity means that "*any relationship observed between two or more variables should be unambiguous as to what it means rather than being due to something else*"(Frankel & Wallen, 2006 p.169). In weak experimental studies, observed difference might only have been caused by unintended variable or variables. The unintended factors that might affect a research are rooted from threats to internal validity. In general, ten types of the threats exist; subject characteristics, mortality, location, instrumentation, testing, history, maturation, subject attitude, regression and implementation (Frankel & Wallen, 2006; Gall, Gall & Borg, 2007; p.382). Subject characteristics effect includes selection of individuals who are different from one another in unintended ways while mortality refers to loss of subjects during the study. Location effect covers impact of the unintended factors related to dependent variable in a location in which data collection or implementation is conducted. Instrumentation effect includes three sub-types; instrument decay; data collector characteristics and data collector bias. In instrument decay effect, instruments might be changed while the study progresses. Data collector

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characteristics effect means that gender, age, ethnicity, language patterns etc. might affect the data features collected by her/him while data collector bias refers to unconsciously distorting the data (Frankel & Wallen, 2006). Testing effect means pre-test use in a research might contribute to the difference between pre-and post test results due to previous practice in pre-test. History effect includes occurrence of one or more unexpected events that are effective on the responses of the participants during the study. As another threat, maturation effect refers to difference in responses on dependent variable of a study due to only passing of time while attitudes of subjects include perceptions of the participants about the study is an important factor to explain results of a study. In regression effect, existence of extremely low and high scores in pre-testing might be closer to mean in post-testing, hence explaining the results is confounded by these scores. As the final one, implementation threat refers to treating experimental or implementation group in a way that gives advantage to experimental group, so the difference between the groups might be due to additional applications and attention (McMillian &Schumacher, 2006 p.135-138).

Taking into account the advantageous of experimental designs to make a research in which more threats to internal validity are eliminated, science education dissertations in Turkey have frequently used experimental designs (Evrekli, İnel, Deniş & Balım, 2011; Calık, Unal, Costu & Karataş; 2008; Karadağ, 2010). Frequent use of experimental designs is not limited to Turkey, when looked at the international literature, it is seen that use rate of experimental methods in educational research is also high (Randolph, Julnes, Sutinen & Lehman, 2008). Alise (2008), in her study, determined that %38 of 63 quantitative educational studies published in high-ranked scientific journals on education included experimental method. Similarly, Kelly and Lesh (2000), by focusing on math and science education, investigated the place of experimental studies in math and science education research and they pointed out that math and science education researchers strictly adhered to experimental methods. Another researcher; Hsu (2005) investigated 2226 articles published in three prominent journals on education from 1971 to 1998, the author found that experimental studies are the most frequently used method in educational research. Although frequency of using experimental designs is high, the studies are weak for making a sound design (true experimental) to overcome threats to internal validity (Evrekli et al., 2011; Sözbilir & Kutu, 2008; Suter & Frechtling, 2000). Since majority of the experimental studies in science education has been conducted by using quasi-experimental designs (Sözbilir & Kutu, 2008; Hsu, 2005). Quasi-experimental design that does not include use of random assignment is not enough to overcome the threats of implementation, testing, history and subject characteristics (Wiersma & Jurs, 2005, p.130; McMillian & Schumacher, 2006, p.278).

For establishing cause-effect relationship on the outcomes targeted in reforms, we are in need of making experimental studies to collect evidence on effectiveness of the reform-based applications. Especially, school-based experimental studies might provide important way of establishing cause-effect relationship regarding to reform outcomes after implementing different methods and techniques (Cook and Sinha, 2006 p.556). But, lack of experimental models or designs for school-wide experimental studies is a problematic area for collecting cause-effect evidence and might be a reason for insufficient number of school-wide experiments (Cook and Sinha, 2006 p.556).

Hence, designing a more comprehensive and powerful way of experimental research is need for science education research attempts in Turkey. Based on this need, the purpose of this study is to suggest a more sound way to establish cause-effect relationship in school-wide experiments and to control more variables which are potentially effective on dependent variables of the science education studies.

PROPOSED RESEARCH DESIGN AND DISCUSSION

True experimental designs are the strongest experimental designs, especially Solomon four-group design has been providing better defense to the threats to internal validity by controlling pre-testing effect, maturation and history (Best & Kahn, 2006, p.183). Solomon design is used for controlling pre-testing effect and for increasing generizability (external validity) of experimental findings (Cohen, Manion, & Morrison, 2007, p.278; Kirk, 2009, p.29; Campbell & Stanley, 1963). But, Solomon four group design does not include a strong strategy or component to check implementation effect. Basic Solomon four group design is illustrated as in figure 1.

	Groups	Randomization	Pre-test	Treatment	Post-Test
Solomon	1	R	O_1	X	O_2
Four Group	2	R	O_3		O_4
Design	3	R		X	O_5
	4	R			O_6

Figure 1. Randomized Solomon four-group design (Braver & Braver, 1988).

In Solomon design, there are four groups, two groups take treatment with pre and post-testing while two groups do not take any treatment. Also in one of the non-treatment groups, both pre-test and post-test are applied although only one post –test application is done in the other non-treatment group (Cohen, Manion, & Morrison, 2007, p.278; Sawilowsky, Kelley, Blair & Markman,1994, Corbetta, 2003, p.106). Spector (1981) stated that Solomon four-group design can be extended to other types of designs by adding more groups than four and applying pre-tests to half of the groups. But, none of them do not consider treatment fidelity due to their focus on only pre-testing effect.

The suggested model in this study is not an extension of Solomon design or other hybrid designs because the main purpose of this model is not to prevent only pre-testing effect or to establish time series measurement. The model focuses on having multiple strategies to prevent internal and external validity threats.

In the suggested model, there are differences from Solomon or other types of hybrid experimental designs such as Swithching Replications Design (Campbell & Stanley,1966, p.202; Ross, Simkhada & Smith,2005). Existence of five groups, purpose of use in school-wide experiments, applications of two pre-testings at the beginning and two post-testings at the end, lack of treatment in three groups, video recording in one experimental and one comparison group during the experimental process for collecting support for treatment fidelity are the most clear differences of the model from previous designs.

The suggested design (Randomized Five-group Koksal's Experimental Design) is a true experimental model in which randomly assigned subjects to five groups are included. Random assignment gives advantages over preventing problems regarding external validity and non-equivalent groups in an experimental study (Currie, 2001). The design has two intervention and three control groups and pre- and post-test applications for two times in three groups have also been inserted into the design. As another component, video recording for three times during the intervention in two of the groups has been anticipated. The proposed design is illustrated in figure 2.

	Groups	Randomization	Pre-tests	Treatment	Post-Tests
Randomized	1	R	O_1- O_2	X	O_3-O_4(RC)
Five-group	2	R	O_5-O_6		O_7-O_8(RC)
Koksal's	3	R		X	O_9-O_{10}
Experimental	4	R			O_{11}-O_{12}
Design	5	R	O_{13}-O_{14}		O_{15}-O_{16}

Figure 2. Randomized Five-group Koksal's Experimental Design
Note: "R"=Randomization, O= Testing, X=Treatment, RC= Video-Recording

In the proposed design, the process progresses as the following; (1) subjects are randomly assigned into the five groups, (2) two control groups and one treatment group take a pre-test, (3) the groups taking the pre-test take the pre-test again two weeks later (Lin *et al.*, 2007), (4) two treatment and three control groups are exposed to different applications, (5) video recording in one control and one treatment group for three times (45 min. for each) during the applications are conducted, (6) all of the groups take post-test, (7) the groups taking the post-test take the post-test two weeks after. All of the processes are done by randomly assigned two implementers (female and male) and two data collectors (female and male).

The design is powerful to overcome subject characteristics effect, maturation, history, mortality, subject attitude and regression effects because random assignment assumes that the subjects who are different, effective characteristics on the dependent variable of the study are presented in the groups in equal probability. Therefore, all characteristics of the participants are also randomly assigned into the groups (Fraenkel & Wallen, 2006). For the mortality effect, random assignment assumes that loss of subjects in treatment groups also occurs in control groups. Moreover, randomly chosen participants in the groups which are not exposed to mortality effect can be excluded to provide comparable groups in the design. The design also provides opportunity to compare different locations by making two different comparisons; the first comparison should be made for the two treatment groups and the second comparison should be done for any difference between the treatment and control groups that are video-recorded.

As for the maturation effect, in addition to random assignment, existence of a control group in the design is a good strategy to check whether any contribution of maturation into the difference in treatment group exists or not. In the proposed design, history effect can also be checked by comparison of the post-test scores of the two treatment groups. As another effect, regression effect can also be overcome by using statistical correction approaches.

In the design, instrumentation effect can be checked and prevented with application of the same instrument by two different data collectors who have different gender during the study and can be evaluated by checking the results on test-retest application and trends in pre-test and post-test applications. Use of two pre-testing and two post-testing is also important for test-retest reliability calculation and to check regression effect. By this way, we can decide about the situation by only checking first pre-test results. At the same time, test-retest reliability for each application can also be investigated by using such a way. Cook and Sinha (2006) explained that multiple pre-testing permits better control over assignment bias and provides valuable information about cause-effect relationship.

In the proposed design, similar to Solomon four- group design, pre-testing effect is checked by using two groups in which no pre-testing is made (Braver & Braver, 1988). Comparison of the scores of these groups with their corresponding groups which take both pre-test and post-test is a strategy anticipated in this study. In Solomon design, implementation check or treatment fidelity aspect is lack. In the proposed design, implementation processes in the control and treatment group are video-recorded for checking the real treatment situations in the groups by using check lists and for making comparisons between the groups. Using video records gives the opportunity of analyzing data over and over again by the same individual or more than one individual (Belg, Borelli, Resnick et. al. 2004). Check list use provides quantitative data to make statistical comparisons between groups and opportunity of making easy analysis on data by different individuals on treatment fidelity. Comparison of different analyses' results gathered by different individuals is also effective to establish reliability and validity of the data collected. But, use of video-recording might cause to Hawthorne Effect (Cook, 1967). To check whether any effect of video recording in two groups occurs, one control group that is video-recorded is also added into the design. Comparison of video-recorded control group and the control group that is not video recorded, but pre-tested gives a base to reach a solution about recording effect. As another strategy recommended in the design, the uninformed implementers in the groups should be assigned by taking into account the gender factor and balancing gender between the groups to reduce the implementer effect.

IMPLEMENTATION

The proposed model can be seen as rigorous and hard to implement, but the potential of the model to control and evaluate internal validity threats is worth to consider it. Cook and Sinha (2006, p.556) have stated that randomized experiments is cost-effective and feasible than other methods in educational research in the long run, because fewer number of randomized true experimental research is needed to establish more valid cause-effect relationship. Cook and Shine (2006, p.556) have also mentioned about lack of studies on school-wide experimental implications. Hence, the proposed model might be used in school-wide implementations on science teaching in Turkey. Especially, reform-based problems requiring experimental investigation might be studied by using this model.

As another important side of the model, it serves as a powerful alternative to Solomon four-group design or other hybrid models due to its fidelity component as an inseparable part of the design. Implementation check is important side of all experimental studies to talk about the results in more confidence and convincing the readers on the results. Therefore, the design gives broader view on the experimental results.

At the same time, the model has only one additional group to traditional four-group experimental model. This situation is an advantage due to the fact that this group is a control group that does not include any treatment so there is no requirement to use more effort to make an additional implementation in the study.

In Turkish dissertation and research studies on science education, experimental studies (chiefly quasi-experimental studies) are the most preferred method (Evrekli et al., 2011; Sözbilir & Kutu, 2008). This situation is an indicator of need to develop and use of more comprehensive and sound experimental designs. By suggesting the model proposed in this paper, it is believed that experimental researchers on science education in Turkey might get opportunity to use more powerful experimental design in their school-wide experimental studies.

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Fen Eğitiminde Yapılan Deneysel Çalışmalar için Geniş Kapsamlı Bir Araştırma Deseni

ÖZ. Deneysel metotlar, değişkenler üzerinde kontrol yapabilme, değişkenleri değiştirebilme ve neden-sonuç ilişkisi kurabilmedeki etkililiğinden dolayı ayrı bir öneme sahiptir. Deneysel desenlerin güçlü yanları yanında iç geçerliliği tehdit eden faktörlere karşı tam koruma altında olmamaları söz konusudur. Türkiye'de fen eğitimi ile ilgili tez çalışmalarının çoğunda deneysel çalışmalar yürütülmesine rağmen, iç geçerlik tehditlerine karşı daha güçlü desenlerin eksikliği önemli bir problem olarak durmaktadır. Bu problem yanında fen eğitimi alanındaki reformların gerektirdiği yöntem ve tekniklerin etkililiğini test etmek için okul çapında yürütülecek deneysel çalışmalara ihtiyaç vardır. Okul çapında yapılacak deneysel çalışmalar, iç geçerlik tehditlerine ilişkin problemlerin üstesinden gelebilmek için daha detaylı ve güçlü araştırma desenlerini gerektirmektedir. Bu araştırmanın amacı daha detaylı ve güçlü bir deneysel araştırma deseni önermektir. Beş gruplu deneysel desen, fen bilimleri eğitiminde dikkate alınan bağımlı değişkenleri kontrol altında tutmada ve neden-sonuç ilişkisi kurmada daha etkili olan, daha fazla sayıda iç-geçerlik tehdidini kontrol etme imkânı sağlayan bir yol önermektedir.
Anahtar Kelimeler: Araştırma deseni, Deneysel çalışmalar, İç geçerliliğe ilişkin tehditler, Fen eğitimi

ÖZET

Bilim, duyusal deneyim yaşama, gözlem yapma, başkaları ile görüş birliğine varma, mantık kullanma ve bir otoriteye başvurma gibi bilgi elde etme yollarından daha geçerli ve daha güvenilir bir bilgiyi elde etme yoludur. Geçerli ve güvenilir bilgi üretimi konusu dikkate alındığında akla ilk gelen unsur bilimsel çalışmalarda kullanılan metotlardır. Bilimsel çalışmalarda farklı metotlar kullanılmaktadır, bunların arasında deneysel metotlar ayrı bir öneme sahiptir. Çünkü deneysel çalışmalar, sebep-sonuç ilişkisinin kurulabildiği, değişkenlerin belirlenip, değiştirilebildiği ve daha fazla sayıda dış etkenin kontrol altına alınabildiği bir yol sağlamaktadır. Çok güçlü özelliklere sahip olmasına rağmen, deneysel metotlar da bir araştırmanın iç geçerliliğine yönelik tehditleri bertaraf etme konusunda tam bir savunma sağlayamamaktadır. Türkiye'de fen eğitimi üzerine yapılan yüksek lisans düzeyindeki çalışmaların önemli bir kısmının deneysel çalışmalar olmasına rağmen, iç geçerliliğe yönelik tehditleri dikkate alan güçlü bir deneysel desenin kullanımında ya da tasarlamasında eksiklikler söz konusudur. Aynı zamanda okul çapında yapılması gereken deneysel çalışmalar da iç geçerliliğe ilişkin tehditlere karşı daha savunulabilir ve daha geniş kapsamlı deneysel araştırma desenlerine ihtiyaç duymaktadır. Bu çalışmada, yeni, daha kapsamlı ve iç geçerliliğe yönelik tehditlere karşı daha güçlü bir deneysel desen yapılandırılmaya çalışılmıştır. Beş gruplu bir deneysel desen olan bu modelde, iç geçerliliğine yönelik tehditlere karşı daha çok önlem içeren, daha hatadan arınık sebep-sonuç ilişkisi kurmada kolaylık sağlayan ve daha fazla sayıda istenmeyen değişkeni kontrol altında tutmayı sağlayan ögeler yer almaktadır. Okul çapında yapılması gereken çalışmalarda, beşinci grubun bir kontrol grubu olması ve daha fazla dış değişkeni kontrol altında tutmada kolaylık sağlaması, mevcut çoklu gruplu desenlere göre daha fazla uygulama kolaylığı sağlamaktadır. Önerilen deneysel desen, şekil 1'de sunulmaktadır.

	Groups	Randomization	Pre-tests	Treatment	Post-Tests
Randomized	1	R	O_1- O_2	X	O_3-O_4(RC)
Five-group	2	R	O_5-O_6		O_7-O_8(RC)
Koksal's	3	R		X	O_9-O_{10}
Experimental	4	R			O_{11}-O_{12}
Design	5	R	O_{13}-O_{14}		O_{15}-O_{16}

Şekil 1. Beş Gruplu Rastgele Atama Temelli Deneysel Desen
Note: "R"=Rastgele atama, O= Test, X=Deneysel Uygulama, RC= Video kaydı yapma

Şekil 1.'de ifade edilen deneysel desen iki deney grubu, 3 kontrol grubu içermektedir. Bu beş gruptan ikisi öntest almamakta, diğerleri ise almaktadır. Tüm gruplar sontest almaktadır. Ön ve son-testler iki hafta aralıklarla yapılan ikili test uygulamalarını içermektedir. Bu durum regresyon etkisinin kontrol altına alınmasını amaçlamaktadır. Aynı zamanda test-tekrar-test güvenirlik hesabı için önemli bir avantaj sağlamaktadır. 3. ve 4. gruplar herhangi bir ön-test almamaktadır, çünkü ön-test etkisini kontrol etmek için, 1. ve 2. grup son test skorlarının karşılaştırılması gereken gruplara ihtiyaç duyulmaktadır. Deneysel süreç ve kontrol grubu uygulamalarını kayıt altına almanın yararı ise, "uygulayıcı etkisini" ve "uygulama süreci" tehditlerini kontrol etmek içindir. Fakat video kaydı yapılması aynı zamanda Howtorn etkisine neden olabileceği için, 1. gruba karşılık gelen bir 5. grubun yapılandırılmasına ihtiyaç duyulmuştur. Ama beşinci grubun bir kontrol grubu olması ve sadece test uygulamasının yapılması var olan deneysel desen örneklerinden, bu desenin zaman ve çaba açısından dezavantajlı bir konuma düşmesini engellemektedir. Sonuç olarak rastgele atamanın yapılması ile sağlanan avantajlara desenin modifikasyonu ile sağlanan avantajlar eklenince, iç geçerliğe ilişkin daha güçlü bir desenin oluşturulması söz konusu olmuştur.