Developing Pre-service Teachers’ Constructivist-Oriented Scientific Epistemological View through Metacognitive Group Discourse

Ivy P. Mejia a *, Sheryl Lyn C. Monterola b

a National Institute for Science and Mathematics Education Development, University of the Philippines, 1101 Diliman, Quezon City, Philippines.

b Division of Curriculum and Instruction, College of Education, University of the Philippines, 1101 Diliman, Quezon City, Philippines.

Abstract

The study investigated the effects of Metacognitive Group Discourse (MGD) on developing constructivist-oriented Scientific Epistemological Views (SEV). Participants were 14 fourth-year pre-service secondary science teachers from a teacher education institute. It utilized a pretest-posttest quasi-experimental design. Participants were randomly assigned to two groups, the treatment group and the control group. Both groups received explicit instructions of the targeted aspects of the nature of science (NOS) and had 14 classroom observations on science lessons. After each explicit instruction of the NOS and classroom observations, only the treatment group underwent a Metacognitive Group Discourse (MGD) while the control group had no any form of group metacognition. SEV scale and open-ended questionnaire were used to assess the changes in the SEV orientations of the participants prior to, after, and two months after the conduct of the study. Results revealed that though there was no significant difference in the SEV of the two groups, both groups’ SEVs still improved. Probing their understanding on the NOS however showed that the treatment group exhibited more constructivist-oriented SEV. Findings of the study imply that the MGD is effective in developing constructivist-oriented scientific epistemological views of preservice teachers and enable its retention and further development. Implications for future research and science teacher education are discussed.

Keywords: nature of science, scientific epistemological views, metacognition, pre-service

1. Introduction

Scientific Literacy has been the main goal of all the reform movements in science education (American Association for the Advancement of Science, 1993; National Research Council, 1996). Essential to this goal is to...
develop an understanding of the nature of science (NOS). The term NOS refers to the epistemology of science that includes values and beliefs that are important to the development of scientific knowledge (Lederman, 1992). Researchers in Asia are investigating ways of assessing views of NOS but have conceptualized it as scientific epistemological view (SEV) (Tsai & Liu, 2005; Tsai & Liang, 2007; Chai, Deng, & Wong, 2010). Scientific Epistemological Views refer to the views of the nature of science, including the assumptions, sources, certainty, justifications, consensus-making and the conceptual development in science (Ryan & Aikenhead, 1992). Characterizations of understanding of NOS and orientations of SEV were found to be similar. Adequate NOS understanding (Lederman, 1992; Abd-El-Khalick et al., 1998) or constructivist-oriented SEV (Tsai, 1998, 1999, & 2002) are exhibited when a student expresses his belief that scientific knowledge is subject to change and that it is derived from observations of the natural world. It is further demonstrated by recognizing that scientific knowledge includes personal background, involves the creation of explanations, affected by culture and is advanced through social negotiations (Lederman, 2007). Inadequate understanding or positivist-oriented SEV, on the other hand, is shown when a student treats scientific knowledge as absolute, ignores the background, imagination, and creativity of scientist as well as the cultural and social factors in the development of scientific knowledge. From the meanings and characterizations of NOS and SEV previously discussed, both constructs are the same. Thus, for the rest of the paper NOS and SEV are used interchangeably. As early as 1960 (e.g. Schmidt, 1967; Carey & Strauss, 1970), researches have proven that teachers have inadequate views of NOS, regardless of the instrument used (Lederman, 2007). Understanding teachers’ views are important because these translate into instructional practices (Tsai, 2007). As a result, influencing pre-service science teachers’ views becomes a major concern for many teacher preparation programs. Relevant research findings suggest that individuals holding an adequate understanding of the NOS are more likely to communicate the nature of scientific knowledge accurately (Bell, Matkins, & Gansneder, 2011; Lotter, Singer, & Godley; 2009). Thus, inclusion of NOS in the pre-service curriculum is deemed necessary. Lines of research suggest that do develop an accurate understanding of the NOS, an effective strategy is through metacognition (Abd-El-Khalick & Akerson, 2009; Peters & Kitsantas, 2010; Yacobian & Boujaoude, 2010). Metacognition means “cognition about cognitive phenomena” or “thinking about thinking” (Flavel, 1979, p.906). Lin & Tsai (2008) stressed that progression to constructivist-oriented SEV must be done metacognitively, which is consistent with the claim that SEV represents one’s awareness of science (Tsai & Liu, 2005). A number of researches on the metacognition of pre-service teachers mostly delved into individual or paired metacognitive activities (Abd-El-Khalick & Akerson, 2009; Lotter, Singer, & Godley 2009). There is a limited literature on pre-service teachers jointly engaging in metacognition by reflecting as a group and regulating their own learning that involves monitoring of each member’s learning. In light of the gaps in knowledge about the teaching of the NOS to pre-service teachers, this study makes use of an explicit approach called the metacognitive group discourse in terms of its effectiveness in developing pre-service teachers’ constructivist-oriented Scientific Epistemological Views.

2. Methodology

The study utilized a pre-test-post-test control group design to determine the effectiveness of metacognitive group discourse in developing constructivist-oriented Scientific Epistemological Views of pre-service teachers.

2.1 Participants

The sample consisted of 14 fourth-years Filipino pre-service secondary science teachers, who all undergraduate students were taking up Bachelor of Secondary Education, major in Physical Science. They have completed 71 units of general education subjects, 51 units of professional education subjects or methods courses and 73 units of science major subjects or content courses. Two (2) of them were male and twelve (12) were female. The participants were grouped into two, the treatment group (TG) and the control group (CG). Each group had one male and six female participants.
2.2 Instruments

2.2.1 Scientific Epistemological View (SEV) scale.

The SEV scale is composed of 32 statements with a Cronbach alpha of .7630. Twelve items of this SEV scale were selected and rephrased statements from Tsai and Liu’s (2005) 19 items SEV scale. The statements are rephrased because Scientific Epistemological View is culture-bound. Respondents of Tsai & Liu (2005) and the respondents of the current study came from different cultures. Filipino respondents have different interpretations of how statements in the instrument were written. The remaining 20 items were developed and added by the authors. The SEV instrument is designed to assess conceptions of the nature of science in five dimensions: (1) the changing and tentative feature of scientific knowledge (CT), (2) the theory-laden quality of scientific exploration (TL), (3) inventive and creative nature of science (IC), (4) the impact of culture (CU), and (5) the role of social negotiations (SN). Each dimension of the SEV is represented by an average of six items using a five-point Likert scale format. Students’ ratings represented their SEVs. For the constructivist-oriented perspective items, a “strongly agree” response has an assigned rating of 5 and a “strongly disagree” response has an assigned rating of 1. In contrast, items stated in a positivist-aligned view were scored in a reverse manner. Students with strong beliefs regarding the constructivist view for a certain dimension have attained higher scores in the subscale. On the other hand, students with positivist-aligned SEVs for a certain dimension had lower subscale scores.

2.2.2 Scientific Epistemological Interview Questionnaire.

As per suggestion of Lederman & O’ Malley (1990), interviews will be conducted with the participants to validate responses. These questions were reworded and rephrased. The SEV interview questionnaire is composed of four aspects of NOS namely: tentative and changing; inventive and creative; theory-laden exploration; and role of social negotiations. Additional questions on differences between observation and inference, and law and theory were added by authors.

2.2.3 Metacognitive Group Discourse Questionnaire (MGDQ).

This questionnaire has two types, the MGDQ-A and the MGDQ-B. Both MGDQ-A and MGDQ-B consist of questions that helped participants to assess, monitor, regulate, and evaluate their understanding towards the targeted aspects of the NOS. However, the MGDQ-B has additional metacognitive prompts that help pre-service teachers to translate their constructivist-oriented SEV in their instructional practice.

2.3 Context and Intervention

The study had two stages, Stage I was the explicit instruction of the targeted aspects of the nature of science to both groups. The two main steps of Stage I were the explicit instructions of NOS aspects to both groups and reflection on the NOS articles. In Stage II, it was the supervision of the pre-service teachers on their on-campus practice teaching and classroom observations. Part of Stage II is the non-supervision of pre-service teachers during their off-campus teaching. During their off-campus teaching, they are free to choose their cooperative schools. No communication happened among the researcher and the participants. The treatment group underwent metacognitive group discourses from Stage I up to the on-campus practice teaching in Stage II. The nature of these discourses is about assessing, monitoring, and evaluating each other’s NOS understanding. The control group, on the other hand, had no any form of metacognitive group discourse activity related to understanding of the NOS.

2.4 Data Collection

For the data prior to, after, and two months after the conduct of the study, the SEV scale was administered, and SEV interview was conducted to the participants. During the metacognitive group discourse (MGD) of Stage I, the
MGDQ-A was used to gather members of the treatment group’s metacognition on aspects of the NOS. For the metacognitive group discourse in Stage II, MGDQ-B was employed to guide the treatment group’s discourses regarding the translation of the NOS understanding into their instructional practice. Each MGD was audio-recorded and transcribed.

2.5 Data analysis

Since the data collected are ordinal in nature, the study used the non-parametric statistics. A two-tailed Mann-Whitney U test was performed on the mean pre- and posttest ratings in the SEV scale. To probe the status of the participants’ SEV, frequency of participants’ characterization of SEV and frequency of types of constructivist understanding obtained from SEV interviews were employed. Moreover, the normalized gain (<g>) score on the SEV test was calculated, which could give an objective measure of learning by taking into consideration the maximum possible increase (Colleta and Phillips, 2005). Since participants’ SEV was repeatedly measured, the Friedman test was performed to identify whether there is an improvement and retention of learned NOS from the participants. These quantitative analyses were then supported by qualitative data using the interview responses, individual, and group post-conferences. The recorded discussions were coded. Thematic analysis was used to draw out participants’ elaborated views and understanding of the aspects of the NOS.

3. Results

3.1 Participants’ Scientific Epistemological Views (SEV).

This section reports the SEV orientation of the participants prior to, after, and two months after the conduct of the study. Participants’ SEV orientation on each aspect in the SEV were characterized into constructivist-oriented, positivist-oriented and a combination of constructivist-positivist orientation. Moreover, subcategories of constructivist-orientation were compared constantly with the contemporary views of epistemology of science based on whether they match the current view or not.

3.1.1 Pre-Instruction SEV

Prior to the study, the SEV of the two groups were comparable (p=.710). Consistent with Tsai’s study (1998, 1999, & 2002), the results based on this SEV scale showed that there were pre-service teachers with constructivist-oriented SEV, positivist orientation, and a combination of constructivist-positivist orientation. Their responses in SEV scale were probed through analysing their interview responses. Table 1 shows the characterization of their interview responses. Sample interview responses are found after the table.

<table>
<thead>
<tr>
<th>Number of questions</th>
<th>Number of responses in each group</th>
<th>SEV Orientation</th>
<th>Frequency of responses from each group</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>84</td>
<td>Constructivist</td>
<td>42 (50%) 42 (50%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Positivist</td>
<td>25 (30%) 22 (26%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Constructivist-Positivist</td>
<td>17 (20%) 20 (24%)</td>
</tr>
</tbody>
</table>

*Constructivist view on changing and tentative nature of science:* Different views on the nature of science were presented according to the SEV of the participants. This is evident in one of the responses: “They will conduct experiments and investigations to prove or disprove the scientific knowledge.” CG-PT11

*Positivist view on role of social negotiation:* The positivist-oriented participant viewed that a scientist works alone to credit inventions solely to him. One participant expressed: “On his own, to prove that they can work alone.” TG-PT6
Constructivist-positivist view on theory-laden nature of science: Constructivist-positivist held a notion that scientific knowledge is a proven expectation of scientist: “It is still your opinion. You already have prior observations that you want to prove.” CG-PT14

The results of categorizing the characterizations of SEV of the two groups in Table 1 showed that their views were more of constructivist-oriented. However, analyses of audio transcriptions revealed that even though they lean towards constructivist view, their status of constructivist understanding have three types: (a) constructivist-oriented SEV with strong understanding (CSU); (b) constructivist-oriented SEV with moderate understanding (CMU); and (c) constructivist-oriented SEV with weak understanding (CWU). Figure 1 summarizes the types of constructivist view of the two groups prior to the study. Views of participants under each group were mostly constructivist and provided explanations that exemplified a moderate understanding. Constructivist Moderate Understanding means that their views are aligned with the aspects of the nature of science but hold insufficient deep explanation in support of these views.

![Figure 1. Frequency of types of Constructivist SEV prior to Intervention](image)

3.1.2 Post Instructional SEV

After the intervention, both groups’ mean score increased (TG=143, CG= 139). However, there is still no significant difference on the two groups’ SEV post-test ($p = .710$). Although there was no significant difference in their SEV, an analysis was extended using the normalized gain to identify which group had a higher gain. Results revealed that the average gain of the treatment group (0.53) is much higher than the control group (0.39). To validate this higher gain of treatment group, their post SEV interview responses were again analysed. The characterizations of their responses are shown in Table 2.

<table>
<thead>
<tr>
<th>Number of questions</th>
<th>Number of responses in each group</th>
<th>SEV Orientation</th>
<th>Frequency of responses from each group</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG</td>
<td>CG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>84</td>
<td>Constructivist</td>
<td>67 (80%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Positivist</td>
<td>2 (2%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Constructivist-Positivist</td>
<td>15 (18%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>64 (76%)</td>
</tr>
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<td></td>
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</tbody>
</table>

Constructivist view on role of social negotiations: Majority of the participants seem to have a broader constructivist view on the social negotiation aspect of the NOS. They understand that scientific knowledge is advanced by many scientists. This is illustrated in one of the responses: “Many scientists work to make the scientific claim stronger.” TG-PT3
Positivist view on inventive and creative nature of science: Some of them still have a positivist view, they assert that scientific knowledge already exists and is only known through discovery: “Knowledge already exists. It is only discovered.” TG-PT4

Constructivist-positivist view on inventive and creative nature of science: For the combined constructivist-positivist view, scientific knowledge is pre-existing, (i.e. they just invent the term or label it). “It is already there, you just need to discover it. It does not need to be created. What a scientist does is to just coin the term or label that phenomenon that they discovered.” TG-PT3

To further examine whether metacognitive group discourse had an impact on the formation of constructivist-oriented SEV among the participants, the responses under the constructivist orientation were categorized into strong, moderate, and weak constructivist understanding. Figure 2 shows that treatment group had a greater progression towards a Constructivist Strong Understanding View with a total number of TG=34 compared with the CG=10.

![Figure 2](image)

**Figure 2.** Frequency of Types of Constructivist SEV after the Intervention

### 3.1.3 SEV two months after the intervention

Table 3 shows the repeated measures of the SEV (pre-test, posttest-1, and posttest-2 two months after the study). Based on Friedman test, only the distribution of the scores of the treatment group showed a significant difference ($p=.004$) compared to the scores of the control group ($p=.062$).

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean Rank</th>
<th>Pre-test</th>
<th>Posttest-1</th>
<th>Posttest-2</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG</td>
<td>1.00</td>
<td>2.29</td>
<td>2.71</td>
<td></td>
<td>.004*</td>
</tr>
<tr>
<td>CG</td>
<td>1.29</td>
<td>2.36</td>
<td>2.36</td>
<td></td>
<td>.062</td>
</tr>
</tbody>
</table>

* $p<.05$

As shown in the increased mean ranks in the three SEV measures of the treatment group, their scientific epistemological views had improved, from 1.00 in the pre-test to 2.71 in the post-test 2 which was two months after the study. On the other hand, there is no evidence that the distributions of scores of SEV pre, post-1, and post-2 of control group are different ($p=.062$). There was no improvement in the SEV of CG participants. They only maintained their views throughout the course of the study and even two months after. To check whether the two groups had retained or changed their view, they were again subjected to a post SEV Interview-2 two months after the intervention. The generated themes of their SEV are presented in Table 4.

<table>
<thead>
<tr>
<th>Number of questions</th>
<th>Number of responses in each group</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>TG</td>
</tr>
<tr>
<td>12</td>
<td>84</td>
<td>Constructivist</td>
<td>66 (79%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Positivist</td>
<td>3 (3%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Constructivist-Positivist</td>
<td>15 (18%)</td>
</tr>
</tbody>
</table>
The themes indicate that participants have constructivist views on most of the aspects of the NOS. However, positivist views and combined positivist-constructivists views on some aspects were retained among the participants. Post SEV interview-2 resulted to almost similar numbers of characterizations of views of the two groups. Surprisingly, improvements on the views of some of the participants under the control group were observed in their explanation during the post SEV interview-2. This change was attributed to a combined grouping in their respective cooperating schools. Pre-service teachers were given freedom to choose their cooperating schools; as a result, the TG participants had to join the other CG participants in the same school that they have chosen. This had contaminated the views of some of the participants under the control group that changed to constructivist views. To examine the changes in views of the two groups, the types of constructivist-orientation from Table 4 were then again subjected to frequency count. Figure 3 illustrates the types of understanding under the constructivist-oriented view of the two groups during the retention SEV interview. The treatment group still had the greater number of Constructivist Strong Understanding (CSU) View with a total number of 32 compared with the control group, which had only 7 CSU.

![Figure 3](image_url)

**Figure 3.** Frequency of Types of Constructivist SEV Two Months after the Intervention

4. Discussions and Implications

In this study, it was found that metacognitive group discourse (MGD) had developed more constructivist-oriented SEVs among the participants of the study. The results showed that even though there was no significant difference in the SEV of the two groups, desirable changes on the SEVs of the TG are still observed. Both groups lean towards a constructivist orientation as an outcome of explicit instructions of the NOS aspects to them. This result is consistent with the findings of Bell, Matkins, and Gansneder (2011) study that NOS progresses towards what is acceptable in science community regardless of the strategies they were exposed to. However, the normalized gain revealed that while both groups improved their views the treatment group had higher average value of gain compared with the control group. This result is supported also from the interview responses of the participants that a higher number of constructivist SEV orientations were found in the treatment group. A greater number of constructivist strong understandings on most of the targeted aspects of the NOS exist also in the treatment group. One interpretation of the result that treatment group had greater constructivist-orientation is attributed to their Metacognitive Group Discourses. It served as an extended activity of the treatment group, which offered an opportunity for them to improve their conceptions about the NOS through discussions and reflective activities with their peers. In contrast, members of the control group never engaged in any group metacognition with their peers and even with the instructor/researcher. This supports the claim of Schwartz, Lederman and Crawford (2004) that participation in NOS discussions other than that employed in the classroom enhances conceptions of the target aspects of NOS. Another important finding of this study is an improved scientific epistemological views of the treatment group two months after the intervention. The factor that can explain this improvement is the routine group metacognition employed by the treatment group during the conduct of the study. The metacognitive prompts and strategies employed in the discourses such as assessing, checking, and elaborating explanations had helped the participants to improve their learning outcomes (Kuhn & Dean, 2004). But on top of this strategy is their collaborative effort to help each other to develop an understanding about the targeted aspects of the NOS. Collaborative and cooperative learning environments were found to be successful in exposing students to
metacognition (Kramarski & Mevarech, 2003; Kuhn & Dean, 2004; Martinez, 2006; Schraw et al., 2006). This means that the goal of the group to develop an understanding on the NOS was enhanced by their cooperation and group support. Thus, they have mostly constructed strong understanding on the targeted aspects of the NOS. Group regulation and monitoring of cognition of the treatment group (Flavell, 1979) through planning, monitoring, and evaluating their understanding during the metacognitive group discourses were significant contributors to the improvement of SEV of the treatment group two months after the study. After the study, metacognitive prompts were no longer part of their routines. However, the participants have already acquired prompting their selves when they meet any form of stimuli about their understanding of the nature of science. The different strategies shared by the members of the treatment group helped them to understand more the different dimensions of SEV. Thus, this study gives support to the notion of Lin and Tsai (2008) that the progression to constructivist-oriented SEV must be done metacognitive. Findings of this study imply that developing a constructivist-oriented SEV is reinforced by providing an opportunity for the students to undergo group metacognition in understanding the targeted aspects of the NOS. Lines of research have recommended an inclusion of NOS in methods course of pre-service teachers will lead to desirable changes in their understanding. However, inclusion of NOS courses does not guarantee that the students will develop a constructivist-oriented SEV. It must be coupled with group metacognition to exposed students on how others think and learned how others understand the epistemology of scientific knowledge. Instructors of teacher education institute, in their roles as a teaching model, should practice metacognition to be more aware on how to understand student’s different paces. As well as to design an instruction that will develop a constructivist-oriented SEV to the students. Further research can also be conducted regarding the metacognitive skills as another variable in the study to examine if metacognitive skills are predictor of scientific epistemological views. It has been observed in the study that participants who spend longer time on individual metacognition provided a more clear explanation during group discussions.

References


