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ORIGINAL ARTICLE

Socioscientific Reasoning Competencies and Nature of Science Conceptions of Undergraduate Students from Different Faculties

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ABSTRACT

Understanding undergraduate students' socioscientific reasoning (SSR) competencies and nature of science (NOS) conceptions are important for them to be informed citizens. Therefore, in this study, SSR competencies and NOS conceptions of 169 undergraduate students from five different faculties were investigated through survey research methodology. The descriptive analysis of the participants' scores indicated that their SSR competencies and NOS conceptions were at a moderate level. The participants struggled most with the dimensions of skepticism and inquiry in SSR and with the dimension of methods and methodological rules in NOS. However, they obtained better scores in perspective-taking in SSR and socio-institutional systems in NOS. When the differences among the faculties were investigated, science students were found to have significantly lower scores on both SSR and NOS. Conversely, health science and engineering students got better scores on both. Finally, there was no significant relationship between SSR and NOS scores of participants. The differences in participants' scores were discussed based on the differences in the curriculums of faculties and implications that were provided for educators. To develop SSR competencies and NOS conceptions of undergraduate students, different departments can collaborate by offering courses from different perspectives to other departments.

KEY WORDS: socio-scientific reasoning competencies; nature of science conceptions; scientific literacy; undergraduate students; survey research

INTRODUCTION

Scientific literacy is widely accepted as an important educational and societal goal (NAS, 2007). There are different approaches for the conceptualization of scientific literacy. Roberts (2007) categorized the approaches about scientific literacy along a continuum between two overarching visions, Vision I and Vision II. In Vision I, scientific literacy refers to having a robust understanding of scientific findings, whereas in Vision II, scientific literacy emphasizes the understanding and use of science beyond the traditional boundaries of science in a broader scope. This involves decision-making in real-life situations related to science and is influenced by other disciplines such as politics, economics, and ethics (Sadler and Zeidler, 2009). In this view, scientific literacy mainly aims to raise socially responsible and competent citizens (Kolstø, 2001). Programme for International Student Assessment (PISA) initiatives aiming to contribute to the quality and equity of learning outcomes for children, young people, and adults also encourage Vision II's scientific literacy (OECD, 2007; Sadler and Zeidler, 2009). According to PISA's definition of scientific literacy, scientifically literate individuals are expected to be "willing to engage with science-related issues, and with the ideas of science, as a reflective citizen" (OECD, 2007. p. 35).

Undergraduate teaching has an important impact on the nation's future (Kober, 2015). Making decisions on complex issues such as new viruses, global climate change, or challenging issues of daily life requires both knowledgeable scientists and engineers and a scientifically literate public (Kober, 2015). According to the National Research Council (NRC, 2011), undergraduate science, technology, engineering, and mathematics (STEM) students need to develop skills to make informed decisions. Therefore, it can be argued that to develop scientifically literate public, STEM-related programs should also consider new ways of teaching and learning in a way that enculturating people to think, to act, to do, and to participate in certain ways (Kober, 2015). It has been argued that currently, STEM-related programs disregard "sociologics" of scientific decisions by emphasizing science and its processes (Zeidler, 2014). These programs consider scientific literacy in the definition of Vision I's scientific literacy. However, it is not unreasonable to assume that a scientifically literate person will have the responsibility to make decisions about policy, research, community, or family (Zeidler, 2014). In such a case, although individuals have the necessary knowledge and technical competence, they would not be inclined to enact that knowledge due to the need for being engaged in subsequent decisions about the physical or social environment. Therefore, while scientific literacy is a prerequisite for making responsible

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decisions, awareness of moral issues is required for scientific literacy (Zeidler, 2014). Developing science-based decision-making skills in controversial contexts including moral issues are a challenge for educators in STEM-related fields (Manske, 2013). Therefore, STEM-related programs of universities need to include ethical and social concerns into their education (Hall et al., 2017).

Socioscientific issues (SSI) provide a fruitful context for including moral and ethical issues in science teaching and learning because socio-scientific decision-making requires scientific knowledge acquisition, nature of science (NOS) understanding, as well as an awareness of moral and ethical issues (Sadler, 2004). SSI are the dilemmas in which both society and science play an important role (Sadler, 2004). Technological developments, such as constructing a nuclear power-plant, gene cloning, and tissue transplant, are examples of SSI that affect society. SSI are open-ended problems that do not have clear-cut solutions. There can be multiple plausible solutions to SSI that are not necessarily determined by scientific considerations (Sadler, 2011). These issues are also influenced by different societal factors, including politics, economics, and ethics (Barab et al., 2007; Sadler, 2011).

SSI can serve as a vehicle for addressing citizenship education (Kolstø, 2001; Zeidler et al., 2005). To specify how this can be accomplished, Sadler et al. (2007) introduced the theoretical construct of socio-scientific reasoning (SSR). According to the researchers, decision-making in the SSI context requires the inclusion of the following four practices:

1. Recognizing the inherent complexity of SSI
2. Examining issues from multiple perspectives
3. Appreciating that SSI are subject to an ongoing inquiry
4. Exhibiting skepticism when presented potentially biased information. (Sadler et al., 2007. p. 374).

First, citizens with SSR competencies should recognize the complexity of SSI. Therefore, practices aiming to develop SSR should avoid sifting a single factor out from the broader context. Instead of restraining the analysis of SSI to a simple cause-effect reasoning, multiple, dynamic interactions of factors within SSI should be recognized (Sadler et al., 2007).

Moreover, SSI reasoning practices require acknowledging the existence of multiple perspectives. Citizens with SSR competencies should recognize the perspectives other than their own standpoint and critically evaluate arguments of each perspective. Argumentation has been considered as one of the most appropriate pedagogies to gain these competencies, as argumentation provides productive pedagogy and assessment schemes for considering counter-arguments from multiple perspectives and providing rebuttals for these counter-arguments (Erduran et al., 2004).

SSI are ill-structured problems; therefore, they are open to social and scientific inquiry (Sadler et al., 2007). Therefore, any citizen with SSR competencies should be in search of specific information about the issue. Congruent with the required thinking style in inquiry, citizens should also be skeptical about the sources of information in SSI reasoning. Since there are multiple perspectives in SSI, citizens should be aware of the potential biases caused by the distortion of data from a particular perspective. They should not accept any information without analyzing it for possible bias.

The graduates of STEM-related departments are candidates to be citizens who have active roles in the decision-making of such controversial issues. Therefore, it is crucial for them to have SSR competencies to enact their knowledge in making decisions on policy, research, community, family, and so on, as responsible citizens.

SSR and NOS

Before explicating the role of the conceptions about the NOS on SSR, it would be better to explain what is meant by NOS. There is not a consensus for the meaning of NOS among philosophers, historians, or science educators. Among science educators, there are seven commonly used characteristics of NOS (Lederman et al., 2002; Lederman et al., 2014). According to this general definition of NOS, scientific knowledge is tentative, empirically-based, subjective, involves human inference, imagination, and creativity, and is socially and culturally embedded. The other two additional aspects are related to the difference between observation and inference, and between scientific theories and laws.

In the past decade, alternative perspectives about NOS have been proposed. The idea of "Whole Science" (Allchin, 2011), "Features of Science" (Matthews, 2012), "Family Resemblance Approach (FRA)" (Irzik and Nola, 2014), and "Reconceptualized Family Resemblance Approach to Nature of Science (RFN)" (Erduran and Dagher, 2014) is examples of these perspectives.

According to Irzik and Nola (2014), FRA has significant advantages over previous approaches to NOS. They conceptualize science as a whole under two themes: Cognitive epistemic system and social-institutional system. Rather than discrete ideas about NOS tenets, FRA proposes a broader, inclusive, and united framework compiled under eight categories. Four of these categories are about science as a cognitive epistemic system, which are scientific activities/processes, aims and values, scientific methodology and methodological rules, and scientific knowledge; while four categories are about science as a social system, which are professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values. The unique contribution of this approach is the emphasis on the differences among scientific disciplines (e.g., relative role of experimentation on astronomy and medicine) as well as the similarities and overlapping characteristics (e.g., naturalism) of different disciplines. Moreover, with the new way of the reconceptualization of the social embeddedness of science, the influence of noncognitive factors (social, cultural, historical, political, and economic factors) on science is highlighted in this approach. Furthermore, contrary to a frozen picture of

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- What is the relationship between SSR competencies (complexity, perspective taking, inquiry, and skepticism) and NOS conceptions (aims and values, scientific practices, methods and methodological rules, scientific knowledge, and socio-institutional systems) of undergraduate students?

METHODS

Research Design and Sample

The survey research methodology was utilized in this study to gather data about undergraduate students' SSR competencies and conceptions of NOS. The participants for this study included a convenience sample of 169 students (18–32 years old), who were from different departments of different faculties in a public university located in Ankara, Turkey. There are nine faculties in this university, dentistry, pharmacology, science, education, architecture, engineering, health sciences, sports sciences, technology, medicine, and applied sciences. To reach undergraduate students from different faculties, data were collected in elective courses offered to students of all faculties. Undergraduate students who were enrolled in these elective courses, from dentistry, science, engineering, health sciences, and technology faculties, were involved in this study conveniently.

All of the participants stated that they had not taken a course in which SSI were discussed. Therefore, they did not have any experience of reasoning on SSI. The demographics of the participants are given in Table 1.

Data Collection

The Quantitative Assessment of SSR (QuASSR) (Romine et al., 2017) and the NOS questionnaire (Kaya et al., 2017) were used for data collection. The survey instruments were administered to the undergraduate students in their classrooms by the author of this study. The approximate time of filling the instruments was 40 min in total. Before administration, the researcher informed the participants about how to fill out the questionnaire. An informed consent form was distributed to each participant before the administration of the instruments. Participants voluntarily agreed to participate in the study. Only after they signed that the informed consent form was they administered the survey instruments.

QuASSR

QuASSR includes two SSI scenarios, each of which has implications for ecology, economics, and the rights of different groups. There are 11 questions in two-tiered ordered multiple-choice format in each scenario. In the first tier, respondents answer a yes/no question. In the second tier, respondents select the best choice that represents the reason for their choice in the first tier. The answers to the second tier questions are composed of three main patterns of reasoning which are assessed on a three-level ordinal scale (0 = low SSR, 1 = moderate SSR, and 2 = high SSR). Different questions aim to assess different dimensions of SSR. There are two items for complexity, two items for perspective-taking, three items for inquiry, and three items for skepticism dimensions. One item only asks for their position on the issue, but it is not rated. The Cronbach's alpha reliability value for the test with the combination of two scenarios was reported as 0.79.

The instrument was translated into Turkish. For translation and adaptation, a back-to-back translation was done. An expert committee including three science education researchers, one of which is specifically an expert in SSI, and one language expert provided their comments on the translated instrument. The translated instrument was administered to an undergraduate student for face validity.

The test was piloted with 73 undergraduate students. Cronbach's alpha reliability value was found to be 0.78 in the pilot study. The reliability value of the test in the current study was 0.82.

NOS questionnaire

To assess undergraduate students' conceptions of NOS, Kaya et al.'s (2017), "Nature of Science Questionnaire" was used. The questionnaire includes five sub-dimensions of RFN. There are nine items in "Aims and Values of Science (AV)," 15 items in "Scientific Practices (SP)," 12 items in "Scientific Knowledge (SK)," 12 items in "Scientific Methods and Methodological Rules (M)," and 20 items in "Social-Institutional Systems of Science (SI)" sub-dimensions. There are a total of 70 items using a 5-point Likert scale format ranging from strongly disagree to strongly agree. The Cronbach's alpha reliability value of the questionnaire was reported to be 0.77.

The test was piloted with 73 undergraduate students. The Cronbach's alpha reliability value was 0.80. The reliability value of the test in the current study was 0.87.

Data Analysis

To answer the first research question, descriptive analysis was performed to figure out undergraduate students' SSR competencies and NOS conceptions. For the second research question, to figure out the differences among undergraduate

Table 1: Demographics of participants

Demographic variables	n	Percent
Gender		
Male	83	49.1
Female	86	50.9
Grade level		
Freshmen	62	36.9
Sophomore	28	16.7
Junior	38	22.6
Senior	40	23.9
Faculty and department		
Dentistry	15	8.9
Science	16	9.5
Engineering	37	21.9
Health sciences	53	31.4
Technology	47	27.8

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students' SSR and NOS scores, a one-way between-group multivariate analysis of variance (MANOVA) was performed. Finally, for the third research question, to investigate the relationships among the dimensions of SSR and NOS, a Pearson product-moment correlation coefficients were calculated.

RESULTS

Descriptive Analysis

Undergraduate students' SSR competencies were explored based on their scores on the QuASSR scale. Participants' mean value was 1.001 out of 2, indicating moderate SSR (Table 2). Participants' SSR competencies were below the moderate level in the dimensions of SSR, except for perspective-taking dimension. Participants had the highest score (M = 1.267) for the perspective-taking dimension. This dimension aims to measure participants' competencies in examining issues from multiple perspectives. On the other hand, they obtained their lowest score for the skepticism dimension. This dimension aims to determine participants' competencies of examining potentially biased information with skepticism.

Moreover, as mentioned, the QuASSR is composed of questions related to two scenarios: Fracking in Pavilion Wyoming and Branville Bay. As the descriptive results revealed, there was not a clear difference between the scores of different scenarios as well as the total score. Similarly, Romine et al. (2017) did not find a variation between the two scenarios. They suggested the consideration of different dimensions as a single construct. Therefore, while investigating differences among faculties, the total SSR scores will be used assuming that each scenario and each dimension equally contributes to the total score.

Undergraduate students' NOS conceptions were measured using Kaya et al.'s (2017) NOS questionnaire, which includes five different categories of reconceptualized FRA. Participants' score on the whole test indicated that (M = 3.60) their NOS understanding were moderate (Table 3). Their scores on different dimensions were close to each other. While participants' score on socio-institutional systems dimension (M = 3.746) was relatively higher than the other dimensions, their score on methods and methodological rules dimensions (M = 3.282) was relatively lower.

Table 2: Descriptive analysis for SSR competencies

SSR dimension/issue	Mean	SD	Skewness	Kurtosis
Complexity	0.992	0.542	−0.147	−0.867
Perspective taking	1.267	0.528	−0.284	−0.679
Inquiry	0.930	0.395	−0.128	−0.345
Skepticism	0.893	0.513	−0.310	−0.486
Fracking	0.995	0.366	0.204	−0.270
Branville	1.008	0.330	0.109	−0.396
SSR	1.001	0.305	0.121	−0.516

SSR: Socio-scientific reasoning, SD: Standard deviation

Differences in SSR and NOS

To answer the second research question, a one-way between-group MANOVA was conducted with two dependent variables (SSR and NOS) and one independent variable (faculty type). Preliminary assumption testing was conducted to check normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity. The results revealed that there was a statistically significant mean difference among the participants from different faculties on the combined dependent variables (F (3, 156) = 4.823, p = 0.000; Wilks' Lambda = 0.785; η^2 = 0.114), indicating medium effect size. When the results of the dependent variables were considered separately, both SSR (F (4, 156) = 6.923, ρ = 0.025; η^2 = 0.155, large effect size) and NOS (F (4, 156) = 2.872, ρ = 0.000; η^2 = 0.071, medium effect size) reached a statistical significance, using a Bonferroni adjusted alpha level of 0.025 (Table 4).

To better understand the differences among faculties in terms of each dependent variable, *post hoc* analysis was performed using Tukey honestly significant difference test (Table 5). Regarding SSR, the lowest mean scores of SSR were found for the science students (M = 0.72, standard deviation [SD] = 0.19) and it is significantly lower than the engineering (M = 1.01, SD = 0.29) and health science (M = 1.15, SD = 0.29) students' scores. Moreover, the health science students' scores were significantly higher than the technology students' scores (M = 0.95, SD = 0.30). The mean scores of the dentistry students were not statistically different from other students' scores.

Similarly, the lowest mean scores of NOS were found for the science students (M = 3.27, SD = 0.35). It was significantly lower than the dentistry (M = 3.58, SD = 0.24), engineering (M = 3.55, SD = 0.38), and health sciences (M = 3.53, SD = 0.31) students.

Relationship between SSR and NOS

Pearson correlation analyses were used to identify the relationship between the dimensions of SSR and dimensions

Table 3: Descriptive analysis for NOS conceptions

NOS dimensions	Mean	SD	Skewness	Kurtosis
Aims and values	3.575	0.458	−0.529	0.427
Scientific practices	3.745	0.435	−0.689	1.236
Methods and methodological rules	3.282	0.313	0.094	−0.123
Scientific knowledge	3.493	0.355	−0.157	0.655
Socio-ınstitutional systems	3.746	0.391	−1.116	1.496
NOS	3.599	0.311	−1.112	1.268

NOS: Nature of science, SD: Standard deviation

Table 4: Follow-up pairwise comparisons for faculty type

Source	Dependent variables	df	F	Sig (ρ)	Partial eta squared
Faculty type	Socio-scientific reasoning	4	6.923	0.025*	0.155
	Nature of science	4	2.872	0.000*	0.071

*ρ<0.025

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of NOS (Table 6). The data pertaining to the dimensions of SSR and NOS were obtained by taking the mean of the related items in the QuASSR and NOS questionnaire, respectively. Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity, and homoscedasticity.

When the relationship between the NOS scores and the SSR scores obtained from the whole scale was examined, it was seen that there was no significant relationship. All of the relationships among NOS components were significant, with varying degrees of strength. Similarly, there were significant relationships among SSR components. However, the relationships among the components of NOS and components of SSR were not significant, except the weak relationship between perspective-taking dimension of SSR and scientific practices dimension of NOS ($r = 0.164$, $\rho < 0.05$).

DISCUSSION

In this study, undergraduate students' SSR competencies and NOS conceptions were investigated. Participants' average score over the whole scale of SSR revealed a moderate SSR competency. However, their competencies on the dimensions of SSR were below moderate, except for perspective-taking dimension. This indicates that undergraduate students were not competent in analyzing the data sources with skepticism.

Table 5: *Post hoc* analysis test results at different faculty types

Faculty types	SSR		NOS	
	Mean	SD	Mean	SD
Dentistry	$0.97^{a*b*c*d*}$	0.19	3.58^{a*}	0.24
Science	0.72^{a*c*}	0.27	3.27^{b*}	0.35
Engineering	1.01^{b*d*}	0.29	3.55^{a*}	0.38
Health sciences	1.15^{b*}	0.29	3.53^{a*}	0.20
Technology	0.95^{a*c*d*}	0.30	3.51^{a*b*}	0.31

Means with the same letters ($^{a, b, c, d}$) are not significantly different from each other; means with different letters ($^{a, b, c, d}$) are significantly different from each other. *ρ<0.05 (two-tailed). SD: Standard deviation, SSR: Socio-scientific reasoning, NOS: Nature of science

Moreover, they had difficulty in recognizing the need for additional data and ongoing inquiry. Undergraduate students also had difficulty in comprehending the complex nature of SSI. They were relatively better at recognizing the confounding perspectives. Romine et al. (2017) also found similar results with college students. Their participants' score was relatively lower for skepticism and inquiry dimensions compared to complexity and perspective-taking dimensions. Romine et al. (2017) stated that complexity and perspective-taking dimensions include the easiest items, while the most difficult items are related to inquiry and skepticism dimensions. Therefore, relatively higher scores on perspective taking and complexity compared to inquiry and skepticism dimensions may be related to their difficulty levels. Similarly, in their study with high school students, Kinslow et al. (2019) found lower mean scores for skepticism and inquiry dimensions.

Qualitative studies investigating SSR competencies also showed similar results. Another study (Owens et al., 2019) with science and mathematics teachers also revealed that teachers struggle to comprehend the need for ongoing inquiry while showing more sophisticated understanding about perspective-taking. Similarly, high school students exhibited sophisticated reasoning about perspective-taking but struggled to recognize the complexity of the issues and the need for ongoing inquiry (Sadler et al., 2007).

Together with the results of other previous qualitative and quantitative studies, the results of this study indicated that skepticism and inquiry are the dimensions of SSR participants struggle with the most. To tackle the historical "siloed" approach to STEM, students enrolling STEM-related undergraduate departments need to be engaged in effective resolution of SSI (Zeidler, 2014). This requires individuals to consider the complexity of the SSI across multiple perspectives, recognize the need for ongoing inquiry as well as to approach the available data with skepticism. As science educators, our goal should be helping students to become critical evaluators of science content (Witzig et al., 2013). Therefore, the awareness of undergraduate students in different faculties should be increased about the possible bias in data in such issues. Media

Table 6: Relationships among SSR and NOS dimensions

SSR/NOS dimensions	SSR	Comp	Persp	Inq	Skep	NOS	AV	SP	M	SK	SI
SSR	1.000	-									
Comp	0.501*	1.000	-								
Persp	0.657*	0.267*	1.000	-							
Inq	0.558*	−0.009	0.167*	1.000	-						
Skep	0.747*	0.148	0.293*	0.217*	1.000	-					
NOS	0.070	−0.006	0.148	0.060	−0.012	1.000	-				
AV	0.015	−0.007	0.029	0.082	−0.045	0.783*	1.000	-			
SP	0.102	0.049	0.164*	0.065	−0.001	0.878*	0.671*	1.000	-		
M	−0.049	−0.145	0.041	0.054	0.124	0.491*	0.250*	0.293*	1.000	-	
SK	0.046	−0.015	0.117	0.099	−0.065	0.790*	0.577*	0.578*	0.338*	1.000	-
SI	0.028	0.015	0.144	−0.036	−0.035	0.859*	0.570*	0.691*	0.283*	0.584*	1.000

SSR: Socio-scientific reasoning, Comp: Complexity, Persp: Perspective taking, Inq: Inquiry, Skep: Skepticism, NOS: Nature of Science, AV: Aims and values, SP: Scientific practices, M: Methods and methodological rules, SK: Scientific knowledge, SI: Social-institutional systems. *ρ<0.05 (two-tailed)

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