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Lessons Learned: Authenticity, Interdisciplinarity, and Mentoring for STEM Learning Environments

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Abstract

In this paper, we discuss the individuals' *roles*, *responsibilities*, and *routine activities*, along with their *goals* and *intentions* in two different contexts—a school science context and a university research context—using sociological lenses. We highlight the distinct characteristics of both contexts to suggest new design strategies for STEM learning environments in school science context. We collected our research data through participant observations, field notes, group conversations, and interviews. Our findings indicate that school science practices were limited to memorizing and replicating science content knowledge through lectures and laboratory activities. Simple-structured science activities were a means to engage school science students in practical work and relate the theoretical concepts to such work. Their routine activities were to succeed in schooling objectives. In university research settings, the routine activities had interdisciplinary dimensions representing cognitive, social, and material dimensions of scientific practice. Such routine activities were missing in the practices of school science. We found that the differences between school and university research settings were primarily associated with individuals' *goals* and *intentions*, which resulted in different social structures. In school settings, more authentic social structure can evolve if teachers trust their students and allow them to share the social and epistemic authorities through establishing mentorship. We do not expect school science students to perform the tasks of scientists in the same manner, yet the desired school science activities should include mentorship roles and interdisciplinary perspectives and encourage school science students to pursue unanswered questions without looking for the right answer.

Introduction

Research in the learning sciences focuses on the cognitive, epistemological, and socio-cultural characteristics of scientific and engineering research communities in their efforts to improve Science, Technology, Engineering, and Mathematics (STEM) education. STEM education is a means to help individuals develop different strategies in order to solve interdisciplinary problems and gain skills and knowledge as they are engaged with STEM related activities through formal and informal learning programs (Sahin, Ayar, & Adiguzel, 2014). In other words, STEM education is a newly adopted paradigm, which engages students in the process of knowledge construction through authentic tasks that investigate real-world contexts and exemplify the scientific work and its enterprise (Ayar & Yalvac, 2010; Chinn & Malhotra, 2002; Roth, 2006). As STEM includes four major components of disciplinary work, it is possible to think about a single discipline or integrated disciplines under the umbrella of STEM education. In the USA, the Next Generation Science Standards (see, Achieve, Inc., 2013) discusses science practice along with engineering practice. The integration of science and engineering disciplines is embedded in the Next Generation Science Standards. In the Turkish science education curricula, this integration is not yet visible, nor being explicitly discussed in the current reform documents (Ministry of National Education [MoNE], 2013). Integration of engineering and science becomes critical when it comes to designing sound STEM learning environment and generating authentic tasks that investigates real-world contexts. Exploring the US and Turkish STEM education contexts will shed light on the differences and similarities between the integrations of the STEM disciplines in two countries.

Many studies have indicated that school science communities are different from science communities (Ayar, Bauchspies, & Yalvac, 2015; Bowen, 2005; Chinn & Malhotra, 2002). While students in most school science communities perform regular class activities such as studying worksheets, completing homework, and conducting laboratory activities, scientists in professional science communities perform scientific investigations, seek funding, debate their scientific claims with their colleagues, peer review, and publish their work. In other words, school science community members are dependent on the knowledge produced by scientific communities, whereas professional science community members challenge that knowledge and strive to generate new knowledge (Ayar & Yalvac, 2010; Duschl, 2008).

We envision the culture of a science classroom as grounded on engagement with the social relationships, materials, and knowledge that members of a classroom construct as they participate in an activity (Middleton, Dupuis, & Tang, 2013; Shepardson & Britsch, 2006). However, in most science classrooms, teachers organize and manage student-learning activities, and establish the social organization of a classroom by means of their *social authority* and *epistemic role* (Berland & Hammer, 2012). In other words, the teacher's institutionalized role determines the norms, rules, and social interactions in the classroom (Bauchspies, 2005), along with the goals and intentions.

Students are regarded as scientifically proficient when they (1) know, use, and interpret scientific explanations of the natural world; (2) generate and evaluate scientific evidence and explanations; (3) understand the nature and development of scientific development; and (4) participate productively in scientific practice and discourse (Duschl, 2007). Yet, at the heart of the problem lies the question of how students can reach such proficiency as they participate in activities within the constraints of a conventional classroom community. This problem seems to be associated with the existing differences between science and school science communities in terms of *social structure*, *practical work*, and *goals* and *intentions*. Social structure, practical work, and goals and intentions can be conceived as the key to designing sound STEM learning environment.

Both in Turkey and in US, K-12 STEM learning environments have not necessarily been designed in consideration to the *routines*, *roles*, and *responsibilities* of the practitioners, or the K-12 students. In the post-secondary education levels in both countries, the STEM learning environments represent different *routines*, *roles*, and *responsibilities* for its practitioners, who are the university faculty and graduate and undergraduate students. The university research settings and school science education settings are two different cultural settings in two different countries.

In this paper we discuss the findings from several studies that explored the nature of science education classroom settings and the university research settings using the ethnographic lenses. Each setting has its own cultural norms to perform any scientific practice within the STEM context. In addition, Turkey and US have some cultural and social differences that might have influenced the contexts of the STEM learning environments in school science settings and in university research settings.

Even though STEM refers to science, technology, engineering, and mathematics as four major components, the perception of STEM itself relatively varies. While efforts and studies in science education can be considered STEM per se, those for integrating engineering into science education can be so. In this paper, we reflect an integrated perception of STEM because of our investigations in the university research settings where engineering and science are both performed through mathematical approaches and computer science. In the university research settings, the STEM notion is more visible. In the K-12 school settings, it is not yet easy to refer to school science education setting as the STEM learning environment setting, yet for the purpose of comparison, we will use them interchangeably throughout the paper.

We draw on a conceptual framework that derived from science and school science studies to answer the following overarching research question:

> *What are the distinct characteristics of science communities that can help us evolve the social structure, practical work, and practitioners' goals and intentions in school science context for designing a sound STEM learning environment?*

We begin by addressing the literature regarding science studies and school science studies that discuss the features of science and school science communities. Then we define our study methods to analyze the characteristics of two school science settings and two university research settings. Next, we present our findings, outlining the features of each setting. Study findings reveal important implications for evolving the *social* *structure*, *practical work*, and *goals* and *intentions* within the context of school science and designing sound STEM learning environments.

Conceptual Framework

Science Studies

Science studies help us understand the vision of science as social practice and explore the norms and characteristics of scientific practice in physics (Pickering, 1995; Traweek, 1988), biology (Buxton, 2001; Lynch, 1985; Roth, 2009), biochemistry (Latour & Woolgar, 1986), engineering (Nersessian, 2006), and nanoscience/technology (Fogelberg & Glimell, 2003; Ruivenkamp & Rip, 2010). Additionally a meta-ethnographic analysis of science studies reveals the prolific aspects of science communities, such as *discourse* and *material culture* (Ayar et al., 2015). These studies indicate that discourse and material aspects of scientific practice are intertwined and represent *authenticity* in science communities.

Pickering (1995) conceptualized scientific practice through intentions, plans, goals, individual interests, and constraints within the framework of '*mangle of practice'* (p.23). According to Pickering, the mangle was the dialectic of *resistance* and *accommodation*. *Resistance*, which momentarily emerges, appears to be an obstacle in the path of a scientist's goal. His or her responses to this resistance would be accommodated through working to solve it in a manner that leads to a new machine or new knowledge. Without human intentions or purposes, there would be no development of new machines or new knowledge.

Buxton (2001) associated *authenticity* of science practice with the ability of a research laboratory's members and their work ethic; this denoted that a member gains the ability to continue doing practical work and to develop dedication to performing contextual practice over time. Yet, Buxton observed a hierarchy among members in the research laboratory. This hierarchy, which resulted from the members' disparate levels of education and expertise, affected the allocation of the workspace. The estimation of success and praise were directly related to individual members' status. Unwritten rules were culturally inherent in the organizational structure of the lab and that of which affected the norms of the lab and the training of the newcomers.

Feldman, Divoll, and Rogan-Klyve (2009) observed that loosely *organized* and *tightly organized* research groups were configured to carry out their research through mutual interactions in a research laboratory's social structure. Over time, a trajectory of personal identities emerged as the research group members progressed their roles from novice researchers to proficient technicians and to knowledge producers. Because the group members differed in their levels of education and expertise, as well as in their researcher experience, a collective wisdom emerged as they engaged in practical work, met regularly, and reported on and critiqued their research. In the research groups, the professors and the advanced students served as mentors time to time.

Paletz and Schunn (2010) juxtaposed the team processes and the social and cognitive framework of multidisciplinary science and engineering groups. They introduced us the *social-cognitive* pathways of multidisciplinary professional groups in two ways: *divergent* and *convergent*. In the *divergent* pathway, team processes included task conflict, sufficient participation and information sharing, and communication norms; while cognitive processes were grounded on information search and analogy. Outcomes of this pathway were originality, elaboration, and quantity or fluency. In the *convergent* pathway, team processes comprised shared mental models, sufficient participation and information sharing, and communication norms. Cognitive processes were only associated with appropriate evaluation. The outcome of this pathway was quality. In both pathways, Paletz and Schunn considered disciplinary and knowledge diversity and formal roles in team structures. The researchers suggested using the power of multidisciplinary teams within the framework grounded on social domain (formal roles, communication norms, sufficient participation and information sharing, and task conflict) and cognitive domain (analogy, information research, and evaluation).

Klein (2005) delineated the complexity of interdisciplinary teamwork by highlighting some key constructs, such as *organizational structure*, *task and activities*, *leadership*, *tools*, and *skills* in science and engineering research groups. Because interdisciplinary collaboration transcends the boundaries of disciplines, the perception of the organizational structure of science and engineering can be complex and interinstitutionalized. Tasks and activities in interdisciplinary teams were grounded on dynamic goals. Their goals drove their tasks and activities. In this respect, the leader's working style was to constrain tasks and activities for performing large interdisciplinary research projects; however the leader of an interdisciplinary team could be gatekeeper, a boundary agent, or a bridge scientist. Through interdisciplinary research projects, members became familiar with the tools and skills inherent in the organizational structure of the team. In sum, the above-referenced studies provide a lens for us to understand and conceptualize *authenticity* in scientific practice. In this regard, *authenticity* refers to the quality of actions (*routines*), *roles* and *responsibilities* assumed in relation to specific *goals* and *intentions* in the knowledge generation process. Such *authenticity* can consist of various characteristics of scientific practice. These studies prompt science education researchers, learning scientists, and curriculum developers to redesign and reshape science learning as a purpose of improving STEM learning environment.

School Science Studies

Students learn science with the help of the knowledge represented in their science textbook and by their teacher. Lectures as cultural events in science classrooms are a means to transfer science subject matter to students. This content is supported through laboratory activities based upon observation and experimentation without challenging others' findings and claims. These activities provide reliable and certain knowledge for students (Hodson, 1998; Rudolph, 2003), as they are engaged in doing simple experiments or demonstrations in which a hypothesis or a research question is provided to them and their teacher gives the directions (Ayar et al., 2015; Chinn & Malhotra, 2002). The lack of uncertainty in these activities leads students to learn to follow the instructions (Roth, 2006), rather than to learn from a given task (Höngström et al., 2010). School science practices may be considered as *safe versions* of scientific practices performed in professional science communities (Archer et al., 2010).

Ford and Wargo (2006) provided a vision of practice through *routines*, *roles*, and *responsibilities* (*3Rs*) to understand authentic disciplinary engagement in scientific practice. Authentic disciplinary engagement was associated with the social and material aspects of science. In this respect, the social aspect of scientific practice referred to collective and individual endeavors as they engaged in scientific practice, while the material aspect of science was grounded in the relationship between human and non-human agents (Pickering, 1995). Thus, the social and material aspects of science practice were characterized in terms of *routines*, *roles*, and *responsibilities* (or the *3Rs*). Also Ford and Wargo (2006) indicated that there was a misalignment between the *3Rs* of scientific practice and those of the practices in science classrooms. To adjust such misalignment, they suggested redesigning science learning environments in a way that amalgamates the *3Rs* of science practice with those of classroom practices.

In this study, we examined the daily activities in two school science settings and two university research settings to identify the dynamics that played a crucial role in the social organization of the school science setting and practice of science. These efforts may be used as evidence to discuss the features of school science and university research settings in tandem as a means to change the *social structure*, *practical work*, and *goals* and *intentions* within the context of school science and design sound STEM learning environment.

Methods

The Settings

This study was conducted in four different settings (Table 1) representing two different contexts: two middle schools settings and two university research settings. These settings were chosen using the convenience sampling strategy because of their accessibility and proximity to the researcher. The first setting was a state school setting in North America. We denoted this setting as *Setting A*. *Setting A* consisted of twenty-two seventh grade students and a certified physical science teacher. Of the twenty-two students, seven were male and fifteen were female. *Setting A* was a space for the teacher and students to perform their everyday activities. The teacher and students met every week at the teaching site (*Setting A*). In other words, the space where the seventh graders received lectures and did laboratory activities was shared with other students. That space was more like a laboratory than a classroom because it included benches, laboratory materials, and equipment. The second setting was a private school setting in a major metropolitan city in Turkey. We denoted this setting as *Setting B*. *Setting B* consisted of eighteen seventh grade Turkish students, a science teacher, and a science lab teacher. Of the eighteen students, eight were female students, and ten were male. *Setting B* had two locations: a classroom and a laboratory. The classroom in *Setting B* was used for lecturing on science topics, and the laboratory was used to demonstrate the knowledge represented in the textbooks with hands-on activities. Even though the students were engaged in well-defined and structured laboratory activities, they were encouraged to work in groups.

Table 1. Characteristics of settings

Characteristics	Setting A	Setting B	Setting C	Setting D
Space	School class	School class + Lab	University Research Lab.	University Research Lab.
Type	State	Private	State	State
Country	US	TR	US	TR
Education Level	Middle School	Middle School	Undergraduate	Graduate
Age Group	11-14	11-14	20-25	>24
# of participants	22 students 1 Science teacher	18 students 1 Science teacher 1 lab teacher	32 undergraduate students 1 faculty member	10 graduate 5 faculty members

The third setting was a physiology research laboratory in a veterinary school at a research-intensive university in North America. We denoted this laboratory as *Setting C*. *Setting C* consisted of undergraduate students, graduate students, and faculty members. During the course of this study, *Setting C* hosted 32 undergraduate students and a faculty member as a researcher and a director. The students were from different majors, such as biology, chemical engineering, aerospace engineering, biomedical engineering, and biomedical sciences.

The last setting was a biological complex systems research center. We denoted this research center as *Setting D*. *Setting D* was established at a research-intensive university in a major metropolitan city in Turkey. *Setting D* consisted of faculty members, visiting scholars, and graduate and undergraduate students. During the course of this study, we worked with five faculty members and ten graduate and undergraduate students. Two graduate (doctoral level) students served as mentors for newcomers. One visiting scholar joined the ongoing project at the time of the study.

Data Collection and Analysis

We collected data through participant observations, field notes, group conversations, and interviews. As a participant observer, the first author spent his time observing members' interactions in the four settings, attending project meetings and class sessions, and talking with the members about their projects and their daily activities. Field notes included each day's happenings, ideas, and impressions, as well as descriptions of the interactions among the members. Our participant observer also conducted semi-structured interviews with fourteen individuals in the research settings and ten individuals in the school settings.

In *Setting A*, we interviewed five students after school hours in their native language, English. Each interview lasted 30-35 minutes. Each student had experience doing science fair projects. Two of them attended regional science Olympiads at the time. We asked open-ended questions to understand students' views about their regular classroom and laboratory activities and the organizational structure of *Setting A*. We interviewed the teacher to explore her instructional strategies in teaching science.

In *Setting B*, five students were purposively selected for interviews in order to learn their views about school science practice; the interviews were carried out in their native language, Turkish. The teacher was asked to talk about her teaching style and strategies, as with *Setting A*. Each interview lasted 30-35 minutes. Each student selected for the interviews had experience with science fair projects before.

In *Setting C*, we purposively selected three undergraduate students and the faculty member for in-depth interviews. Two interview participants—Glory and Alice (pseudonyms) were novice researchers; they reported that they had never conducted any scientific research, nor had they participated in a research program. Glory was a sophomore, and Alice was a junior in the biology department. Glory was involved in the experimental aspect of research. The third participant–Angel (a pseudonym)—reported that she was a part of a research interest section related to the theoretical aspect of research; she was a junior in the biomedical science department.

In *Setting D*, we studied a culture of engineering researchers that included two faculty members, two doctoral students, five master's students, and the visiting scholar. One of the two core faculty members was the director of *Setting D* and a chemical engineering professor. The other was the vice-director of Setting D and also a chemical engineering professor. Both faculty members had worked at *Setting D* for the last ten years. The visiting scholar in this study had previously worked with the former director of *Setting D*, and she was employed as a biology professor at another university at the time of the study. There were two doctoral students with chemical engineering backgrounds. Both had more than four years of experience at *Setting D* and held master's degrees in chemical engineering. Five of the master's students were pursuing degrees in chemical engineering. Four of the five master's students had chemical engineering backgrounds, and one of them had both a chemical and a genetic engineering background. We interviewed the engineering researchers in their native language, Turkish, for a total of sixty minutes. All formal interview questions were open-ended and semi-structured. The informal interviews usually took place at *Setting D* during coffee breaks and lunch, and these ranged from 5 minutes to 30 minutes. Both the formal and the informal interviews were audio-recorded.

We analyzed a variety of data using ethnographic data analysis methods (LeCompte & Schensul, 2010) and a constant-comparative method (Glaser & Strauss, 1967). We employed ethnographic data analysis methods as participant observations were conducted simultaneously, while we analyzed the data from interviews, field notes, and documents via a constant-comparative method. To establish trustworthiness (Lincoln & Guba, 1985), our participant observer spent his time observing each setting. He spent one semester observing *Setting C* and *Setting D*, whereas *Setting A* and *Setting B* were observed for a period of one year. We crystallized data from the participant observations, field notes, and artifacts with the interviews (Richardson & St. Pierre, 2005).

Findings

We organize our findings along the features of school settings and university research settings in terms of *roles*, *responsibilities*, and *routines*, all of which represent the nature of *social structure*, *practical work*, and *goals and intentions* in each setting. The findings highlight the similarities and differences among the four settings, which in turn help redesign and reshape STEM learning environment in school science context.

Roles, Responsibilities, and Routines in School Settings

We observed that teachers in both *Setting A* and *Setting B* had common roles and responsibilities in teaching science. Both teachers acted in authoritarian and facilitator roles. Their authoritarian sides were evidenced throughout the regular classroom activities, such as lectures. They generally grounded lectures on interactions between the teacher and students, using them to transfer the knowledge represented in science textbook to the students. In some cases, the lectures turned into whole-class discussions, when some of the students brought up different ideas about the concept being taught, as well as when a conflict existed among the students: for instance, why eroding is an example of both chemical and physical change. Meanwhile, the teachers established their lectures according to an Initiation-Response- Feedback (IRF) interactional sequence as a means to motivate students to participate in discussing the science topics.

The teacher of *Setting A* adopted a facilitator role when students were engaged in laboratory activities. These activities were associated with the lectures already given. In other words, students were taught science content through lectures, and then they engaged in laboratory activities to relate the theoretical knowledge to practical work. Therefore, we conceived of laboratory activities as *confirmatory*, rather than exploratory.

We observed an emerging difference in *Setting B* when the students were engaged with laboratory activities. In *Setting B*, we witnessed the existence of a laboratory teacher whose role was to prepare laboratory activities in coordination with the classroom teacher. In other words, the laboratory teacher was expected to test every laboratory activity and share its results with the classroom teacher before students came to the laboratory. When the results were not relevant to the concepts being taught, the content of laboratory activity was revised immediately. Such collaboration was intended to provide students with a well-prepared laboratory sheet and to minimize the potential problems that might occur during the experiment. When students performed the laboratory activities, the lab teacher was responsible for monitoring their behavior and learning. The role of the lab teacher in *Setting B* was as a guide, and her responsibility was to become a bridge between theory and practice. However, the classroom teacher also existed physically in the laboratory and visited each group to follow what was happening and what they were doing.

There were similarities in the roles and responsibilities of the students in *Setting A* and *Setting B*; however, their roles varied, as they were involved in different interaction modes. The roles of the students were limited to listeners, receivers of knowledge, and note takers when their teachers were the center of action during the whole-class discussions. Rarely, they challenged the knowledge presented by the teacher. Both teachers established whole-class discussions through IRF sequence, which depends on the interaction between student and teacher. As a result, no social network of interactions among the students emerged. The students in *Setting A* and *Setting B* moved to the center of the action when they worked in small groups, where they had a chance to discuss concepts and challenge their ideas. Therefore, during the whole-class discussions, they were passive, whereas they were more active during small group work. These roles in fact determined their responsibilities. During lectures, their responsibilities were limited to memorizing and recalling the knowledge represented and to following each topic discussed, whereas their responsibilities changed during lab activities in such a way that they felt motivated to complete their laboratory tasks because they were at the center of action.

In sum, these findings indicate that the practices of school science were memorizing, recalling science content knowledge through lectures, and carrying out laboratory activities to confirm that knowledge. Simple-structured science activities were a means to engage students in practical work and relate the theoretical concepts to such work. The students were not expected to generate scientific claims. In other words, the goals and intentions of the students in the school science context were to learn scientific knowledge that was represented either by their teacher or in their textbook. They were motivated to engage in laboratory activities in order to experience the scientific investigation process. The routines in the school science context determined the individual roles and responsibilities. During lectures, teachers were on the stage and were responsible for organizing instructional materials to teach the science topics. Students, as receivers took the responsibility to learn scientific knowledge and memorize that knowledge to confirm the results obtained through lab activities. The laboratory activities enabled both students and teachers to take on different roles and responsibilities. While the teachers were facilitating and monitoring the students' activities, the students had the responsibility to complete their tasks through a division of labor. Yet, their routines were discipline-based and limited to lectures and confirmatory laboratory activities, rather than challenging scientific claims. These routine activities were a means for them to succeed in schooling objectives one way or another.

Roles, Responsibilities, and Routines in University Research Settings

We observed two distinct research groups configured by the faculty member in *Setting C*: (a) a *research interest group* and (b) a *topics/goals group*. In the research interest group, students focused on content knowledge and mathematical modeling practices. They were motivated to come up with a research question to answer in the near future. In turn, they would display what they were interested in. In the *topics/goals group*, students concentrated on experimentation and mathematical modeling practices. They were asked to develop a research hypothesis, conduct an experiment, present findings, and write an abstract; all of these would be finalized in a research report. Their main purpose in this case was to understand and explain the performance of a bat's cardiovascular system through mathematical modeling. In both groups, we observed different interaction structures, such as student-student and student-faculty, as they were generating the mathematical models. Such interactions were a way to communicate with one another in order to discuss and share their findings, ideas, and problems.

In *Setting C*, the members of both groups were expected to attend all meetings, including bat labs, team meetings, and group workshops, under the auspices of the faculty member. They used an online communication platform to maintain contact with each other at the times they were not in the lab. This platform provided a means for them to share the difficulties they encountered, the scientific results they found, the solutions they might generate, and some surprising observations they made.

The student researchers worked in a collaborative manner in *Setting C*. They comprehended that collaboration enabled them to change their research topics or goals. Indirectly, such collaboration was a way to generate new questions to study other topics or goals. For instance, Glory stated, "Meeting with different study groups and asking questions helped me find solutions to problems with my work, and other students had better ideas to answer my questions." Alice associated collaboration with the background of other student researchers. Given that she was a biology student, she did not have enough information concerning certain mathematical concepts; however, for example, group members from aerospace or biomedical engineering departments were more competent in the mathematical aspect of their project. She added, "Collaborating with them provided support for me to understand the mathematical issues."

In *setting C*, the student researchers utilized mathematical modeling to comprehend and conceptualize a bat's cardiovascular system, rather than memorizing and recalling the mathematical formulas and equations represented in their textbook. A technology-enriched bat laboratory was a space for student researchers to examine how live bats' cardiovascular system works through a remote-controlled microscope. Student researchers were provided with an opportunity to develop their questioning skills as they constructed their mathematical models on the computer. The faculty member frequently mentioned, "I am a researcher and have no pedagogical background," so she preferred using intuitive techniques over the semester. That is to say, she did not want to transfer structured knowledge to the student researchers directly. Instead, she adopted the notion of '*learning by doing'* to allow student researchers, particularly biology or biomedical science students, to comprehend how mathematics functioned in their project. Hence, research and learning was situated through questioning and interacting with student researchers as they were engaged in mathematical modeling practice.

We observed and associated *interdisciplinarity* in *Setting C* in terms of the *routines*, such as mathematical modeling, analogy with electric circuits, and biological experimentation. Such interdisciplinarity comprised cognitive, social, and material aspects. As the cognitive aspect, mathematical modeling was used to understand the relationship among several parameters, such as blood flow rate, temperature, metabolic rate, and diameter and length of vessels. The structure of an electric circuit was used as an analogy to study the cardiovascular system of bats. Using a remote-controlled microscope, student researchers conducted experiments to examine the characteristics of the cardiovascular system of bats. As the social aspect, the student researchers worked in research-specific groups. The director allowed student researchers in the research interest group to show their specific topic interests. They collaborated with each other through face-to-face and online communications. The student researchers in the topics/goals research group worked together and conducted experiments through a remote-controlled microscope and generate mathematical models. We related the material aspect to the mathematical models, the artifacts derived from snapshots of interesting or unusual features and phenomena, the texts that emerged during communications, the manuscript archive, and a remote-controlled microscope connected to a computer.

In *Setting D*, we observed two different research groups associated with the faculty members' working style. We characterized the research groups as *distributed* and *centralized*. In the *distributed research group*, the faculty member organized weekly meetings and regular group discussions with her graduate students (doctoral and master's students). To regulate the *routines* in her research groups, one doctoral student was assigned to help newcomers (i.e., master's students) adapt to the practices of the research center community. She spent time with the newcomers in one-on-one interactions; sometimes she gave lectures and presented background information and skills, and sometimes she guided the master's students in conducting a project with support from the faculty member. We viewed this doctoral student's role as a bridge between newcomers and the faculty members. In the *centralized research group*, the second faculty member established one-on-one meetings with her research group members. One doctoral student in her research group was assigned as a teaching assistant to help the faculty member organize and follow her teaching activities. Thus, such differences between the two faculty members allowed doctoral students to take on different roles and responsibilities.

In *Setting D*, the researchers carried out their work in an office environment through routine activities such as conducting a literature review, extracting protein models from the Protein Data Bank [PDB], manipulating these models via algorithmic functions and techniques, and generating new models via simulations and three-dimensional visualization techniques. All of these were used to predict complex protein-folding dynamics. These routines had *interdisciplinarity* associated with social, cognitive, and material aspects of scientific practice (Nersessian, 2006; Paletz & Schunn, 2010). The cognitive aspects related to familiarity with the theoretical background, the PDB (consisting of protein structures experimentally obtained from crystallography) and the knowledge to perform algorithmic programming and visualization tools, and to generate and interpret theoretical and computational models and simulations using different approaches (e.g., molecular dynamics and Monte Carlo) to reconstruct and better understand protein structures. These approaches were essential in designing the three-dimensional computational models of proteins.

The material aspects in this case were related to models and devices (e.g., supercomputers). The *Setting D* members created protein models via supercomputers. These models were experimentally developed and stored online. The faculty and students could easily access these models. Based upon a common interest and research question, they rearranged the structure of models. The product of creating these models and simulations was a deeper understanding of protein complex systems and scientific explanations that helped to develop a better foundation for important decisions in carrying out their contextual practice.

We associated the social aspects in this case with *collaboration* and *mentoring*. Collaboration was the key element for sustaining learning and research in the sense that the research group members, who had different levels of expertise, experience, and competence, performed a shared practice. The master's students came to the

Setting D with different content knowledge, experience, and skills. For instance, a student with a genetic engineering or a computer engineering background offered the opportunity for a research group's members to relate genetic concepts to computational science through algorithmic functions. The doctoral students in this setting had more experience than the master's students, and they were already familiar with the content knowledge and skills used in understanding the structure of protein models. The master's and doctoral students worked on a project under the supervision of the faculty members. In addition, the doctoral students had established a *collaborative partnership* with various scholars in foreign countries such as the US and EU with the help of the faculty members at the center. Similarly, the faculty members developed such partnerships with many scholars from different countries. They expressed, "The main purpose behind these partnerships was that we learn from each other and work in tandem to contribute to our study field through our research papers." In other words, their partnership supported them in the knowledge generation process. Thus, the research groups at the *Setting D* mainly included master's students, doctoral students, and faculty members who performed their contextual practices in a collaborative manner.

In *Setting D*, the research group members studied computational biological systems regardless of their experience, knowledge, and age through mentorship. Furthermore, newcomers to the *Setting D* with differing background information, and some came from different majors. Their mentors (e.g., doctoral students) played a meaningful role in helping the newcomers adapt to the interdisciplinary culture at the *Setting D*. Through mentor supervision, a mentee may acquire knowledge and skills, as well as how to use the common language to become a member of the research center, to gain experience in conducting research and to perform as a contributing member. In other words, the mentorship process allowed master's students to move towards the center of action, meaning that they led projects under their mentor's guidance and developed accountability over time. Meantime, the mentors gained project management skills on their trajectory toward becoming faculty members. One mentor stated, "Helping newcomers adapt to our routines and conduct their project in the center was important for me because becoming a faculty member is my next step after my doctoral study."

In sum, study findings revealed that they assumed roles as researchers, and their responsibilities were taken seriously in working toward a common goal. More specifically, the student researchers in *Setting C* gained research experience over time and collaborate with each other in order to complete their tasks. In *Setting D*, graduate students gained the ability to perform their contextual practices as they became familiar with the rules, norms, and content knowledge used in *Setting D*. The more experienced researchers took responsibility for mentoring the newcomers. *Routines* had interdisciplinary perspectives representing the cognitive, social, and material dimensions of scientific practice. The cognitive aspects of routines in *Setting C* were related to mathematical modeling, analogy, and experimentation, whereas the routines in *Setting D* had computational modeling and visualization dimensions. The social aspects that emerged in *Setting C* and *Setting D* revealed collaboration and mentoring. Both *Setting C* and *Setting D* had common the material aspects of scientific practice related to models, artifacts, and devices.

Discussion

In this study we aimed to bring to the fore the various characteristics of science and engineering communities and to highlight the *roles*, *responsibilities*, and *routines* of scientific practice and those of classroom practice along with their *goals* and *intentions*. We discuss these characteristics in terms of *authenticity*, *interdisciplinarity*, and *mentoring* and suggest ways to change *social structure*, *practical work*, and *goals* and *intentions* to improve STEM learning environments within the context of school.

Authenticity

We characterize *authenticity* with respect to *roles*, *responsibilities*, and *routines* of scientific practice or authentic science (Ford & Wargo, 2006), along with *goals* and *intentions* (Pickering, 1995). We conceived of *routines* as everyday tasks or activities. We observed common routines, such as familiarizing with and memorizing science concepts, doing simple laboratory experiments in a group, and confirming science content knowledge with laboratory activities in both *Setting A* and *Setting B*. In *Setting C*, the routines involved understanding and conceptualizing science content knowledge for conducting research; performing modeling practices; and writing an abstract; all of which represented the elements of a research proposal (e.g., hypothesis, methods, findings, and conclusion). In *Setting D*, the most common routines included following the recent literature, extracting protein models from PDB, generating models via computational functions and techniques, running algorithmic functions, and simulating and visualizing protein structures in three dimensions.

We viewed the routines of each setting as *contextual* (Roth & Hsu, 2014), because individuals were driven to perform their routines relevant to their setting. In other words, the instructional activities and science content represented were relevant to *Setting A* and *Setting B*, in which students were learning science topics. *Setting A* was a space for both becoming familiar with and learning science topics and doing laboratory activities, whereas *Setting B* comprised a combination of classroom and laboratory portions. Students were taught science topics in the classroom portion of *Setting B*, and science content knowledge were confirmed through laboratory activities during the laboratory portion. In both *Setting A* and *Setting B*, the students were engaged in understanding content knowledge and doing laboratory experiments with the help of their teachers. Similarly, *Setting C* was a laboratory space used to understand science content knowledge and answer research questions as the researchers were engaged in experiments using a remote-controlled microscope. Their routines were associated with the laboratory setting itself, where individuals performed theoretical and experimental activities to understand the cardiovascular systems of bats. *Setting D* was an office-oriented space where individuals worked on their computers and performed computational practices to understand the structure of proteins through computational practice and visualization. The routines were relevant to each setting context per se (Pea & Maldonado, 2006). Therefore, we did not expect to observe the routines of the school settings (Setting A and Setting B) resembling those of the university research settings (Setting C and Setting D), because the students performed the *safe versions* of scientific investigations to conceptualize science content knowledge in a school laboratory that had limited resources and equipment (Archer et al., 2010).

The individuals in the *Settings* were engaged with content adapted to their settings (Pea & Maldonado, 2006). The science content represented by teachers or textbooks in both *Setting A* and *Setting B* had already been generated by communities of scientists. In *Setting A* and *Setting B*, students were not expected to generate new knowledge or contribute to the fields of science and engineering. However, they were expected to become familiar with science content, to use it as they engaged in laboratory activities, and to relate it to their daily lives in order to conceptualize how natural phenomena occur around them. In other words, students in *Setting A* and *Setting B* were engaged in activities that simulated practices of science in a *safe mode* (Archer et al., 2010). In *Setting C* and *Setting D*, individuals were involved in projects under the supervision of their professor or mentors. The individuals were implicitly or tacitly expected to contribute to science and engineering and to generate new knowledge. Although they were engaged with science content represented by their professors or mentors or in textbooks, their efforts to perform scientific investigations would also contribute to other studies in one way or another. Therefore, they needed to transcend the content as they sought to answer their research questions.

We can link the differences between the *3Rs* of school and research settings in terms of *contextuality* and *content adaptivity* to the *goals* and *intentions* of the individuals in each setting. On the one hand, our findings indicated that the goals and intentions of students in school settings were limited to becoming familiar with ready-made scientific knowledge and conducting safe versions of scientific investigations to confirm that knowledge. Students used their knowledge and inquiry skills to proceed on their trajectories of becoming students of science. On the other hand, the goals and intentions of members in research settings were to perform scientific investigations to challenge scientific claims and to contribute to science and engineering. Members used the related knowledge and gain experience and skills to develop their learning and research, which in turn helped them proceed on their trajectory toward becoming more experienced researchers in science and engineering.

We associated the roles and responsibilities of the individuals in each setting with routines performed over time. Routines drove roles and responsibilities in a social context (Ford & Wargo, 2006); in this respect, there were differences between the school and research settings. On one hand, as teachers were expected to organize instructional activities in both *Setting A* and *Setting B*, their epistemic authority over students was always dominant and inherent in the social structure of classroom. Among the roles of teachers were knowledge giver, instructional activity planner, and facilitator; whereas the roles of students were of knowledge receiver, listener, note taker, instructional activity player, confirmer, and rarely challenger. The responsibilities of the teachers and students varied were based on these roles. While the teachers were responsible for organizing, managing, and controlling the teaching and learning activities through their epistemic and social authority, the students were responsible for performing the tasks given by their teacher and preparing for science exams. On the other hand, the roles of the faculty members in *Setting C* and *Setting D* were of facilitator, guide, and mentor. Because the faculty members tended to share their authority and wanted their students to gain research experience, individuals were given roles of project leading and of challenging concepts, ideas, and problems. In fact, this comprised part of the researcher education in *Setting C* and *Setting D* (Feldman et al., 2009). Unlike *Setting C*, the more experienced individuals (e.g., doctoral students) in *Setting D* were given a chance to mentor newcomers. This role allowed them to assume responsibilities such as completing their projects, collaborating, and sharing their findings with others. Thus, epistemic and social authority (Berland & Hammer, 2012) over individuals was shared in both *Setting C* and *Setting D,* which in turn enabled individuals to conduct their projects and rely on collective wisdom in order to reach their common goals.

Interdisciplinarity

Interdisciplinarity is associated with “the integration of concepts, philosophies, and methodologies from the different fields of knowledge” (Derry & Schunn, 2005, p.xiii). Interdisciplinarity becomes inevitable when practitioners, scientists, and engineers seek to answer a question or solve a problem in a collaborative manner. In other words, interdisciplinarity provides individuals with a platform where they generate strategies and solutions using their diverse knowledge backgrounds, experiences, skills, and methods.

We did not observe such *interdisciplinarity* in *Setting A* or *Setting B,* because students and their teachers were engaged with science discipline only and their goals and intentions were limited to learning science and learning about science through lectures and confirmative laboratory activities. However, their daily practices sometimes required them to work in a collaborative manner. When students were involved in laboratory activities in both *Setting A* and *Setting B*, they were encouraged to collaborate with one another in order to complete the activities and make sense of the tasks given on their laboratory sheets. The idea behind these activities was simply to allow students to gain experience with teamwork, share their knowledge and skills with others, and learn from each other. The tasks given to students groups did not have any interdisciplinary perspective, nor did they require them to use their experience and knowledge with other disciplines (e.g., mathematics or engineering). Therefore, we did not observe such interdisciplinarity school settings.

We observed *interdisciplinarity* grounded on *goals* and *intentions* (Klein, 2005) in *Setting C* and *Setting D*. Individuals were engaged in practices of understanding the cardiovascular system of bats through mathematical modeling in *Setting C*. Understanding and conceptualizing bats’ cardiovascular systems through building an analogy between the cardiovascular system and an electric circuit required individuals to comprehend electrical, biological, and mathematical aspects of interdisciplinary knowledge. The groups configured in *Setting C* included many individuals with different backgrounds, such as biology, chemical engineering, aerospace engineering, biomedical engineering, and biomedical sciences. Each group had a sense of shared purpose, knowledge, and skills to perform contextual practices in understanding how the cardiovascular system of bats works and how they respond to instant changes in the system. Similarly, various research groups were configured in *Setting D*, where different paradigms, methods, and knowledge of many disciplines were employed (Klein, 2005). The researchers in *Setting D* utilized various methods, such as Monte Carlo, Molecular Dynamics, and Machine Learning from different fields (e.g., machine learning is used in electric and electrical engineering) to understand the structure of protein models. As with *Setting C*, each group in *Setting D* had a mutual goal to pursue and developed a sense of sharing their methods, findings, and tools with each other as they performed computational practices and visualized protein structures.

Within the framework combining the social and cognitive domains of the interdisciplinary team process (Paletz & Schunn, 2010), *Setting C* and *Setting D* displayed the features of interdisciplinary teamwork because students had a formal role as novice researchers, whereas the faculty member’s role was as a facilitator and a researcher in *Setting C*. We observed different formal roles in *Setting D*. The faculty members were director and researcher. The doctoral students were relatively more experienced researchers (i.e., mentors) as compared to the master’s students. However, both the doctoral and the master’s students were considered as researchers. In both *Setting C* and *Setting D,* the members were encouraged to participate substantially in the weekly meetings and lectures where information was shared among members. Through these meetings, conflicts or problems were negotiated; and findings were evaluated in regards to the research questions and purpose. Meanwhile, different communication structures were established in research groups in *Setting C* and *Setting D*. While communications were limited to student-student and student-faculty in *Setting C*, communications emerged among student-student, student-mentor, student-faculty, mentor-faculty-student in *Setting D*, all of which represented the process of interdisciplinary collaboration.

Mentoring

Mentoring is viewed as relationship between a mentor (one with more experience and knowledge) and a mentee (one with less experience and knowledge who needs support) in general. Mentors can be advisers, supporters, tutors, masters, sponsors, or models of identity (Guberman, Saks, Shapiro, & Torchia, 2006). Mentoring can be a means to enable newcomers or mentees to adapt values, practices, and knowledge in a community of science (Nakamura, Shernoff, & Hooker, 2009). In the present study, mentoring was a tacit norm in *Setting D*, as with Feldman et al.'s (2009) study. Naturally, the more experienced and skillful individuals were expected to help newcomers in understanding the methods, tools, and knowledge used in *Setting D*, in completing their projects, and in solving the social and emotional problems they encountered through their interactions. Although mentoring was time consuming, the mentoring process was a milestone for doctoral students on the trajectory of becoming faculty members in the near future. Such a process was not visible in *Setting C*, because there were no tacitly assigned doctoral students for mentorship. The student researcher groups were configured under the supervision of the faculty, and students mutually interacted with each other as they were engaged in tasks. *Setting A* and *Setting B* were similar to *Setting C* in that the teachers did not initiate a mentoring process. Instead, they acted as facilitators to organize instructional activities, such as learning science topics and performing safe versions of scientific investigations.

Conclusion

In this study we discussed the social structure of school science and university research in regard to *roles*, *responsibilities*, and *routines* along with *goals* and *intentions* pertaining to *contextuality* and *content adaptability*. Our attempt has been to transform the social structure of school science settings in order to attain sound STEM learning environments in school context. We did not aim at revealing that science or engineering communities outperform school science communities in doing science and engineering practice. We wanted to learn from the science communities about the authentic scientific practices and their social and cultural norms. We envisioned using the lesson learned for designing sound STEM learning settings in school science contexts. We noticed that routines drove the roles and responsibilities in both of these settings. We related the differences to the goals and intentions relevant to context and content of each setting. On one hand, in the school settings, the goals and intentions of teachers were to teach students science, to organize their instructional activities, and to monitor their learning progress; while those of the students were to learn science topics and learn about science through lectures and safe versions of scientific investigations in order to succeed in their schooling objectives. On the other, in the research settings, research group members sought to answer a research question or solve a problem in order to contribute to science and engineering, as well as to develop strategies and methods to generate their scientific claims. They organized and managed different research groups regardless of age, knowledge and experience level. They shared their roles and responsibilities to maintain learning and research. The novice researchers involved in this process were trained to become researchers in science and engineering over time. Therefore, there is need to change the goals and intentions of individuals in the school settings in such a way that they should go beyond succeeding in their schooling objectives and become familiar with the skills, strategies, and methods that scientists or engineers use and develop in pursuing unanswered questions; although we do not expect students to act as scientists or engineers.

The differences in the goals and intentions between school and research settings result in different social structures. The social structure of school settings is grounded on student-student and student-teacher interactions; student-student interactions lead to collaboration when they are engaged in confirmatory laboratory activities. The social structure of the university research settings is richer in the sense that various interaction patterns among the research settings members emerge due to the interdisciplinary aspects of their routines. The goals and intentions in the school settings are limited to schooling objectives for specific terms (one or two semesters). Yet, in the university research settings the goals and intentions can be extended over more than two semesters, because these goals and intentions depend on the project span and the funding received. To reach these goals and intentions, research groups are configured regardless of age, experience, and expertise. Meanwhile, mentoring is promoted to help newcomers adapt to the culture of the research setting, to proceed on the trajectory of becoming a researcher, and to reach a common goal. To change the social structure of school science classroom, the epistemic and social authority of teachers should be shared with the students, and mentoring should take place in school science in consideration of students' knowledge level and skills when they are engaged in laboratory activities. That is to say, the social structure can be changed if teachers trust their students and provide them with a chance to share social and epistemic authority through establishing mentorship. The interdisciplinary aspects of social activities in the research settings provide new insights for science educators and learning scientists to improve the design of practical work in school settings.

As we learned from the research settings examined here, contextual practices had various dimensions and were interdisciplinary. Such characteristics enabled research group members to study a specific topic through more than one disciplinary background. To solve a problem or answer a question, they utilized science content knowledge alongside mathematical knowledge, engineering content knowledge and so on. We advocate that school science activities should encompass mentorship roles and interdisciplinary perspectives and encourage students to pursue unanswered questions without looking for the right answer.

Authenticity, *interdisciplinarity*, and *mentoring* are three essential concepts in designing sound STEM learning environment in school context because these three concepts serve as impetus for evolving the traditional nature of school science. We support the idea of integrated STEM education in a Turkish context in ways that students spend efforts to solve a real-world problem, which requires content knowledge and skills in science, engineering and mathematics; that they utilizes many aspects, philosophies, approaches, and strategies to seek unanswered question; and that they learn from one and another through mentoring, which is tacit norm in communities of science and engineering.

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