STEAM PRACTICES IN CHEMISTRY EDUCATION

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Abstract

STEM is the process of integrating science, technology, engineering and mathematics in education. STEAM differs from STEM by a letter of 'A' which means arts, on the basic logic of science and arts mustn't be decomposed from each other. This research aimed to assist tenth-grade students in learning through their own constructed materials for bringing up them as well-qualified individuals by using chemistry, technology, engineering, popart and mathematics (STEAM) integration which would improve their creativity and critical-thinking too. 33 tenth-grade students from a high school in Turkey participated in this qualitative research in 2015-2016 academic year. Student constructed materials, and student process evaluation worksheets were used as data collecting tools. Content analysis was utilized for the gathered data. Content analysis was cross-checked for the reliability of the research too. The results showed that students' creativity and critical-thinking skills were enhanced through such a STEAM process, and this process was also helped to educate well-qualified individuals in the abovementioned fields.
Keywords: *chemistry education, critical thinking, educating well-qualified individuals, STEAM.*

Introduction

Today, thanks to advances in technology, accessing information has become quite easy. Regardless of the technological improvements, the individuals need to think creatively so to make plausible decisions which would make them compete in business domains later. Because of these factors, it is so essential for bringing up individuals who had the true understanding of how nature of science works and how they could use their creativeness trough learning science. Among all science disciplines, one of the most difficult found one is chemistry because of the submicroscopic nature of matter (Nakhleh, 1992). In particular, the ability to use chemistry-specific terminology in communication, to make evidence-based predictions, and to apply this knowledge to daily life problems, is essential which would be possible only with properly constructed chemistry teaching domains.

Nowadays the acronym STEM - shorthand for science, technology, engineering, and mathematics - has quickly taken hold in education policy circles for a basic guide for constructing teaching domains, but some experts in the arts community and beyond suggest it may be missing another initial to make the combination still more powerful. The idea? Move from STEM to STEAM, with an A for the arts (Robelen, 2011). The achievement of realizing a synergic balance between arts and science in the teaching practices with STEAM is so important for effective constructions of teaching domains. While the disciplines of arts and science have not been hierarchized and no distinction exists between them in the ancient Greek in order of teaching, the question persists: Why not to adopt a similar approach into current society? (Piro, 2010).

Science, technology, engineering, and mathematics (STEM) training prepares individuals for the labor market, whereas integrating arts into STEM improves students' creativity, moves individuals beyond stereotypes, and break taboos (Boy, 2013). A dynamic understanding of science, technology, engineering, arts, and mathematics (STEAM) provides individuals with problem-solving and critical-thinking skills, and builds their self-confidence too (Maeda, 2013). With STEAM, students create their own portfolio texts so that their knowledge is as current as possible and they solve real-life problems that empower them as well as deeply seed their knowledge in multiple ways for transference (Yakman & Hyonyong, 2012, p. 1083). In other words, what would STEAM based teaching domains contribute to science education and how could such teaching domains be constructed? First, creativity of students in science, art and engineering could be enhanced through such a process. Second, creative invention programs that students prefer to take could be applied to regular school curriculums. Third, audio-video textbooks in class for a better understanding and display of actual output before design would help students to make something that is more real and creative. Forth, researchers should also be given opportunities to participate in such teaching domains and also to learn from other researchers. Fifth, supportive materials for assisting how to design a STEAM integrated material could be made available in classes. Sixth, an upgraded version of the teaching domain must be applied for the following teacher domain so creative skills could be nurtured (Kim & Park, 2012).

If you integrate IT (information technologies) to STEAM education environments, you could get an attractive educational method for the digital generation students to easily and pleasantly learn the contents of sciences, technology and mathematics. The educational methods that integrate IT and other fields of academia have been attempted before STEAM education. In addition, the reason for a brighter footlight for IT as the transition from STEM education to STEAM education occurs is that it occupies a large section in the field of Art in the digital era (Park & Ko, 2012, p. 321). From another perspective, one could integrate robotics to STEAM education environments just as the previous study too. As a fact, arts promote and develop creativity while making feel beauty and joy (Chung, 2014).

As a summary it could be said that STEAM learning aims to develop student interest, facilitate the integrated understanding of science, technology, engineering, arts, and mathematics, and develop problem-solving skills through real-world applications (Jeong & Kim, 2015, p. 1322).

Problem of the Research

'How to build a chemistry teaching domain on the basis of STEAM practices?' was determined as the problem of this research just because there was found a gap in literature about STEAM practices in chemistry educational researches. There were studies in literature about STEAM practices, about complex machine designs, logo programming integration, engineering based social practice, climate change monitoring program, robotics art (Chung, 2014; Guyotte et al., 2014; Jeong & Kim, 2015; Kim & Park, 2012; Park & Ko, 2012) but STEAM practices about chemical education were not so common. This research would also model the integration of a STEAM practice in chemistry education for teachers, academicians and also for further studies.

Research Focus

This research aimed to make tenth-grade students learn through their own constructed materials related to STEAM integration in order to educate them in this field. It was intended to enhance individuals' creativity and critical-thinking skills by the help of the process.

Research Methodology

Model

In a qualitative research, data collecting tools such as observation, interview, and document analysis are utilized. Its process is to reveal perceptions and cases in a realistic and holistic way (Yildirim & Simsek, 2008, p. 39). As a qualitative model, the case study approach allows a deep investigation into a case which is subjective, complex, and functional (Stake, 1995, p. 1-2). According to another definition by Yildirim and Simsek (2008, p. 79), a case study is a qualitative model that analyzes a case within its own boundaries in a holistic way. For a more specific definition, a case study is an intensive study of a case (Glesne, 2012, p. 30). This research intensively investigated tenth-grade students' learning success through a STEAM integrated material development process and its effectiveness on creativity and critical thinking.

Participants

A total of 33 tenth-grade students from a secondary school in Turkey during the academic year of 2015-2016 participated in this research. The participants were selected through purposeful sampling with the criterion that they must have been educated in the department of graphics and photography. This sampling technique provided students the opportunity for integrating art, specially selected pop art into their STEM education; that is to say, the STEAM integration. It also provided students the opportunity for integrating their content knowledge about graphics and photography into STEAM. In qualitative researches it was necessary to explain the research's context. So, the high school was located in the center of Ankara district and was for girls-only. Interactive technology was not used in this high school during the academic year in which the research was conducted. The participants were in the mid-achieving group, according to the 'passing the high school exam' and their parents were from the middle socio-economic level. The researcher was a middle-aged female with a postgraduate degree in the department of chemistry education and had eleven years of teaching experience.

Data Collecting Tools and Data Collecting Process

The student constructed materials and students' process evaluation were used as data collecting tools. Content validity of the data collecting tools was checked by two science educators. The coding and categorizing consistency among the same educators were used for the reliability of the data collecting tools. For the validity of the research, students' process evaluation was used.

For the ethics, the participants were informed about the research process before the application. There was no student who was not willing to participate in the research process, so the research was conducted with all of the tenth-grade students from the same classroom of the high school that was selected through purposeful sampling. The participants were told that they could withdraw from the research at any time. They were also told that if they withdrew from the research, they would still be included in the teaching process; however, their data would not be used. The participants' real names were not used due to ethics; thus, each participant was coded.

During a seven hour data collecting process, the students learned through their own constructed materials through STEAM integration and illustrated the common components of national high school chemistry curriculum (2013; 2018). The students drew chemical compounds (science component of STEAM) on a canvas with gouache paints and brushes (technology component of STEAM) using popart (arts component of STEAM) in three-dimensional molecule structure (engineering component of STEAM) and in appropriate geometry (mathematical component of STEAM). Following the material construction period, the students evaluated the teaching process.

Data Analysis

Content analysis can be described as a data analyzing tool that can be applied to a great variety of discourses. Foremost, this analyzing method can be described as a controlled interpretation effort (Bilgin, 2006, p. 1). In this research, content analysis was utilized for the gathered data. Codes and categories constructed then frequencies were calculated.

Research Results

The results of the research were interpreted under two subtitles: Student constructed materials and students' process evaluation.

Student Constructed Materials

Content validity of the student constructed materials was checked by two science educators. The students drew chemical compounds on a canvas with gouache paints and brushes using popart in three-dimensional molecule structure and in appropriate geometry. The paintings were coded, categorized and then frequencies were calculated. Cross-content analysis was utilized too (Erickson, 2004). In other words, the content analysis was cross-checked whether all the categories consisted of all the codes or not. The codes, the categories and the frequencies were presented in Table 1. Frequencies were denoted by the letter 'f' in the table.

Table 1. Student constructed materials.

Student Paintings			
Categories	Codes		*f*
	Molecule Formula	Molecule Name	
Drawings of Organic Compounds	CH_4	Methane	3
	C_2H_6	Ethane	6
	C_3H_8	Propane	3
	C_4H_{10}	Butane	1
	C_5H_{12}	Pentane	1
	C_7H_{16}	Heptane	1
	C_8H_{18}	Octane	1
	C_9H_{20}	Nonan	1
	$C_{10}H_{22}$	Dean	1
	C_2H_4	Ethylene	1
	C_3H_6	Cyclopropane	1
	C_4H_8	Cyclobutane	3
	C_6H_{12}	Cyclohexane	1
	C_6H_5OH	Methyl alcohol	1
	C_6H_6	Benzene	1
	C_6H_5OH	Phenol	1
	$C_6H_5NH_2$	Aniline	1
	$C_{14}H_{10}$	Anthracene	1
	$CO(NH_2)_2$	Urea	1
	$C_{13}H_9N$	Acridine	1
Drawings of Inorganic Compounds	H_2O	Water	1
	CO_2	Carbon dioxide	1
	CCl_4	Carbon tetrachloride	1
	NH_3	Ammonia	2

As can be seen in Table 1, the students drew 24 different chemical compounds with a total of 36 paintings, on canvas with gouache paints and brushes using popart in three-dimensional molecule structure and in appropriate geometry. The reason for the difference between the number of participants and the total number of frequencies is that some students drew multiple paintings. In order to support the results in Table 1, some of the students' paintings were presented at Figures 1, 2, 3, 4, and 5. Coded student was denoted by the letter 'S'.

Figure 1. A three-dimensional and tetrahedral popart drawing of the C_2H_6 (ethane) molecule on canvas by participant S5.

As could be seen from Figure 1, the student drew C_2H_6 (ethane) molecule (science component of STEAM) on canvas with gouache paintings and brushes (technology component of STEAM) using popart (art component of STEAM) at a three-dimensional version of the molecule as a double-tetrahedral (engineering component of STEAM) with appropriate bond angles as $109,5^0$ (mathematical component of STEAM).

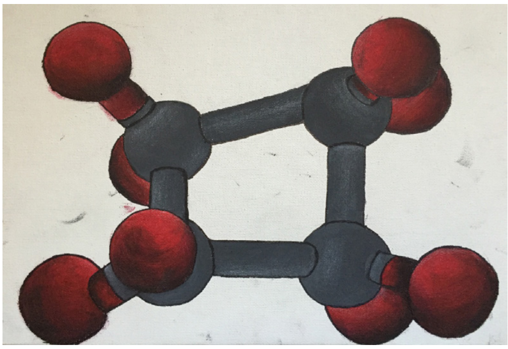

Figure 2. A three-dimensional and cyclo popart drawing of the C_4H_8 (cyclobutane) molecule on canvas by participant S16.

As could be seen from Figure 2, the student drew C_4H_8 (cyclobutane) molecule (science component of STEAM) on canvas with gouache paintings and brushes (technology component of STEAM) using popart (art component of STEAM) at a three-dimensional version of the molecule as a cyclic organic compound dissimilar to the compound at Figure 1 which was straight-chain organic compound (engineering component of STEAM) with appropriate bond angles, with an interior bond angle less than 90^0 (mathematical component of STEAM).

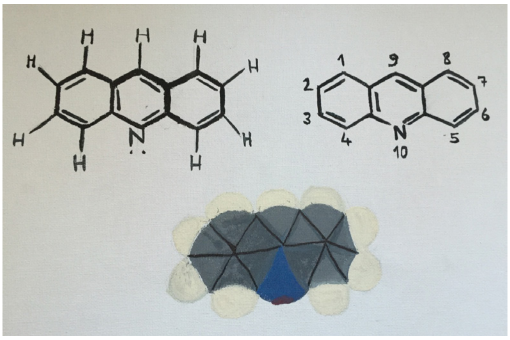

Figure 3. A three-dimensional and planar popart drawing of the $C_{13}H_9N$ (acridine) molecule on canvas by participant S28.

As could be seen from Figure 3, the student drew $C_{13}H_9N$ (acridine) molecule (science component of STEAM) on canvas with gouache paintings and brushes (technology component of STEAM) using popart (art component of STEAM) at a three-dimensional version of the molecule as a planar compound (engineering component of STEAM) with appropriate bond angles, with an interior bond angle of nearly 120^0 (mathematical component of STEAM).

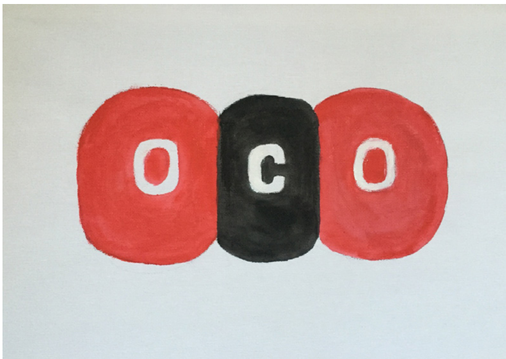

Figure 4. A three-dimensional and linear popart drawing of the CO_2 (carbon dioxide) molecule on canvas by participant S4.

As could be seen from Figure 4, the student drew CO_2 (carbon dioxide) molecule (science component of STEAM) on canvas with gouache paintings and brushes (technology component of STEAM) using popart (art component of STEAM) at a three-dimensional version of the molecule as a planar compound similar to the compound at Figure 3 (engineering component of STEAM) with appropriate bond angles, with a bond angle of 180^0 (mathematical component of STEAM).

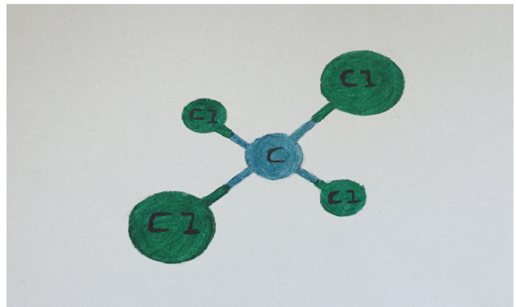

Figure 5. A three-dimensional and tetrahedral popart drawing of the CCl_4 (carbon tetrachloride) molecule on canvas by participant S7.

As could be seen from Figure 5, the student drew CCl_4 (carbon tetrachloride) molecule (science component of STEAM) on canvas with gouache paintings and brushes (technology component of STEAM) using popart (art component of STEAM) at a three-dimensional version of the molecule as a tetrahedral similar to the compound at Figure 1 (engineering component of STEAM) with appropriate bond angles, with a bond angle of $109,5^0$ (mathematical component of STEAM).

Students' Process Evaluation

Following the material construction period, the students evaluated the teaching process. Content analysis was utilized for the students' process evaluation data. Codes and categories constructed then frequencies were calculated. Cross-content analysis was utilized too (Erickson, 2004). The codes, the categories and their frequencies were presented at Table 2.

Table 2. Students' process evaluation.

Categories for STEAM Components	**Codes**	***f***
Chemistry component of STEAM	Meaningful learning by critical thinking	12
	Acquiring new knowledge	1
Technology component of STEAM	Integrating the graphics and photograpy content knowledge into STEAM	6
Engineering and mathematics components of STEAM	Encouraging the investigation of molecule structure, molecule geometry and bond angles	1
Popart component of STEAM	Enjoyable	27
	Motivating	10
	Creativity	2
	Different	2
	Time-saving	1

As can be seen in Table 2, the students emphasized the chemistry component of STEAM (meaningful learning by critical thinking, f:12; acquiring new knowledge, f:1), the technology component of STEAM (integrating to graphics and photography content knowledge into STEAM, f:6), the engineering and the mathematics components of STEAM (encouraging the investigation of the molecule structure, the molecule geometry and the bond angles, f:1) and the popart component of STEAM (enjoyable, f:27; motivating, f:10; creative, f:2; different, f:2; time-saving, f:1). In order to support the results in Table 2, some quotations from students' process evaluation were presented below:

*S21: It provided me an enjoyable learning (**enjoyable**). It also provided me permanent learning (**meaningful learning by critical thinking**). It helped me to demonstrate the molecule structure in my mind (**creativity**). It did not take too much time to construct the materials, it was practical (**time - saving**).*

*S24: I liked to construct the materials (**motivating**). Integrating my own creativity to field in which I have been educated made the STEAM integration practice more enjoyable for me **(integrating the graphics and photography content knowledge into STEAM, enjoyable, creativity).***

Discussion

This research provided tenth-grade students with assistance in constructing materials related to STEAM integration in order to educate them as well-qualified individuals. All of the drawings illustrated chemical compounds (chemistry component of STEAM) on a canvas with gouache paintings and brushes (technology component of STEAM) by using popart (art component of STEAM) in a three-dimensional structure (engineering component of STEAM) and in the appropriate molecule geometry and bond angles (mathematics component of STEAM) so it can be said that this STEAM integration practice enhanced the students' creativity and critical thinking ability.

This result of the research 'STEAM practices increased creativity and supported critical thinking ability,' was also supported by the results obtained from the students' process evaluation by the codes of critical thinking (f:12) and creativity (f:2). Besides, most of the students found the use of popart in the STEAM practices enjoyable (f:27) and motivating (f:10). Another dimension highlighted by the student evaluation was that the STEAM practices enabled the integration of the students' graphics and photography knowledge with the content knowledge of chemistry (f:6). Learning content knowledge of chemistry by making arts also could cause a deeper understanding of chemistry. As a premise for this finding, one of the student's saying from Guyotte et al.'s study (2014), "*I did this... and I did that... I know this... because I did that,"* could be given.

In different countries efforts have been made to integrate critical thinking into science curricula, recognizing that it is necessary to live in a plural society with citizenship competence (Vieira, Tenreiro-Vieira and Martins, 2011, p. 43). And then well-qualified individuals who can think, question, criticize, and predict can be educated. Therefore, they would be able to compete in the labor market. According to the student constructed materials' evaluation and students' process evaluation, this research revealed that STEAM practices supported students' critical thinking ability just as the target mentioned in the literature presented above. As a different premise for this finding, Jeong and Kim's study

(2015) could be given, in which they found that STEAM practices made individuals scientifically literature citizens in society.

This research was presented a STEAM illustration for further studies, since the STEAM practices are new in educational circles and there is a gap in the literature regarding this issue. Increasing the STEAM practices in the science curriculum in different countries can be suggested for further studies. As one of the teachers suggested at Henriksen's study (2014, p. 2), *"Most people tend to simply equate creativity with a particular art form. If you can draw, you're creative. Or if you're musical, then you're creative. But it's much more broad than that… the best scientists are highly creative. The best mathematicians are extremely creative,"* the STEAM practices in science curriculum's importance is inevitable.

Conclusions and Implications

This research modeled an illustration of how to build a chemistry teaching domain on the basis of STEAM practices for researchers, teachers and academicians. It would be meaningful to emphasize the main conclusion of the research as 'STEAM integration practice enhanced the students' creativity and critical thinking ability'. As a last emphasis it would be beneficial to give meaning to STEAM. What did we do best with a STEAM integration practice? For example, was not it possible in chemistry classes to make students give their attention for mathematics; for a chemical compound's bond angles? The answer was 'a STEAM practice in chemistry education gave opportunities for students to gain interdisciplinary view by integrating technology, engineering, arts and mathematics into science, chemistry so to gain creativity and critical thinking ability.

This research aimed to use chemistry - technology - engineering - popart and mathematics integration, which would enable students to construct materials and to become well-qualified individuals by improving their creativity and critical thinking because STEAM can help make good education better. The STEAM framework, like steam itself, can fit anywhere and take innumerable shapes, and if used purposely can be a very powerful and enjoyable tool for teaching and learning any level of any topic (Yakman & Hyonyong, 2012, p. 1084).

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Received 11 February 2019; Accepted 28 May 2019

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