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Examining the Quality of Art in STEAM Learning Activities

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The practice of the science, technology, engineering, arts, and mathematics (STEAM) education has bettered the science, technology, engineering, and mathematics (STEM) learning to a more advanced level. However, although the other four areas (S, T, E, and M) have been extensively integrated into learning activities, the inclusion of the arts (A) has often been considered as merely an approach to improve the esthetics of an artifact/product. We recruited three experts to examine 62 selected STEAM learning activities from Taiwan, in which the quality of the five areas of S, T, E, A, and M and the meanings of the A within the learning activities were examined. We propose that the A in the STEAM acronym may stand for three different roles: arts/esthetic learning, contextual understanding, and creativity. Results showed that the areas of technology, engineering, and creativity were presented with deeper knowledge, whereas the other topic areas (science, mathematics, arts/esthetic learning, and contextual understanding) were presented with limited knowledge. Specifically, the contextual understanding, which represented practices that promote the reflection of others' life situations or the sociocultural context, contained lower quality than that of all other areas. Evidence indicated that most STEAM activities in Taiwan failed to incorporate the sociocultural context to pose more unique questions to humanity. Furthermore, it is found that compared to individual authors, the collaboration of team authors improved the qualities of STEAM activities. Examples of the STEAM activities with and without the arts are offered. The implications of providing instructions for STEAM learning are discussed.

Keywords: arts education, arts/esthetic learning, contextual understanding, creativity, STEAM

For modern citizens, it is critical to transcend subject boundaries and adopt a transdisciplinary approach, and in particular to integrate the sciences and arts so as to explore or solve complex problems. After investigating 33 countries and their economics status, the Organization for Economic Co-operation and Development (2016) found that adults who are highly proficient in literacy, numeracy, and problem solving are more likely to have better job opportunities, higher job satisfaction, and greater well-being. However, over 20% of adults had poor numeracy skills and one in four adults lacked confidence in using computers, revealing the importance of including more individuals in science, technology, engineering, and mathematics (STEM) learning. Yakman (2010) has stated that the arts are an essential element to achieve this goal. Other educational organizations have urged that the arts be prioritized alongside STEM due to their significance at various learning levels (e.g., National Advocates for Arts Education, 2018). In 2011, Steve Jobs emphasized the integration of the arts and technology in the product launch of iPad 2: "It is in Apple's DNA that technology alone is not enough—it's technology married with liberal arts, married with the humanities, that yields us the results that make our heart sing." If individuals gain a comprehensive view of art knowledge, they are more likely to engage or reengage with science learning at a later date, appreciate different cultures, consider social values within scientific developments, and become global citizens (Lee et al., 2012). However, the arts seem to be marginalized within STEM learning contexts (Clapp & Jimenez, 2016). Meanwhile, as teachers had absent or limited knowledge about the meanings of arts, it is difficult for them to include the arts in science, technology, engineering, arts, and mathematics (STEAM) activities (Herro & Quigley, 2017). In

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Taiwan, many STEAM activities have been on the rise since 2011, but the roles and meanings of the arts among these activities remain unknown.

In STEM learning, the arts play a critical role (Boy, 2013; Han et al., 2017; Leysath & Bronowski, 2016), but some studies found them to have been marginalized or neglected (Clapp & Jimenez, 2016; Perignat & Katz-Buonincontro, 2019; Yakman, 2012). Han et al. (2017) suggested that arts could be situated at the initial or core place of a work, instead of merely a decoration of the end product, indicating that we should value the arts and avoid regarding them as subservient to other subjects. However, Clapp and Jimenez (2016) investigated the presence of STEAM disciplines with 60 maker-centered learning activities and found that the dimension of esthetics was about 50%, whereas art and creativity were only 20–30%, which were all far below the average percentage of STEM subjects (71%). They found the implementation of arts was limited, such as the STEM-with-stickers effect and the artless STEM effect. The *STEM-with-stickers* refers to activities emphasizing the superficial decoration of products with a lack of arts involvement. This effect casts the arts as a supplementary element, conveying STEM essence by visualization (Sousa & Pilecki, 2013). For example, the activity of making a passive phone speaker might merely incorporate art discipline in the form of allowing students to decorate their works with color pens or an electric engraving pen. Besides, the artless STEM effect is a prevalent trend in which the activity involves only STEM learning and the arts are not involved at all.

Some activities have successfully implemented deeper knowledge of arts and integrated them with STEM content in the past, even though yielding challenging works. Clapp and Jimenez (2016) provided an example, the "Traditional cigar box guitar" by Mark Frauenfelder in magazine *Make*. This activity allows young makers to understand the fundamental mechanics of stringed instruments and their musical qualities by making a handmade guitar. The author explained the design by deconstructing the critical parts of the guitar (e.g., body, bridge, frets) and clarifying their functions (e.g., sound resonance, vibration transfer, note production). In this way, a deeper discussion of science and math-related conceptions was provided, and the understanding of basic musical conceptions was also improved. Furthermore, the author explained the effect of voice using several tools and technologies and also encouraged readers to be creative by trying alternative materials to make their own guitars. In general, this activity is successful because it focuses on all areas of STEAM by taking the arts as a core focus and intensifying STEM learning. The second example is Chung et al. (2018), which also implemented profound knowledge of arts in STEAM learning. They developed a 15-week STEAM-6E course based on the theme of creative design of IoT (Internet of Things) assistant devices for the elderly. The procedures for this special course were emphasized and illustrated and included the stages of preparation, engagement, exploration, explanation, engineering, enrichment, and evaluation. Though they lack a definition of "A," several arts-related conceptions were revealed in the learning stages. In the exploring stage, for instance, students were asked to collect information about the topic, exchange opinions with peers, and be aware of the potential needs of the elderly as essential references for designing assistant devices. This design could provoke thought and deepen the understanding of the social context, thereby creating a work of emotion and warm feeling. One of the groups considered it necessary to reduce the burden of caregivers to the elderly arising from the increased demands of long-term care services in this society. Thus, they designed multifunctional somatosensory clothes that included various functions (e.g., heartbeat sensor, GPS positioning, built-in somatosensory adjustment) to increase care quality and efficiency.

The two examples mentioned above demonstrate that it is possible to integrate artistic elements into STEAM activities, but they belong to different categories. The "traditional cigar box guitar" is a product activity from the maker's community, whereas Chung et al.'s (2018) study is a curricular activity in an instructional setting. There are no sharp divisions between the two kinds of activities, because a curriculum could also lead to a product. However, the goal of a product activity often emphasizes completing a work step-by-step over a few days, whereas in contrast, the goal of a curricular activity focuses more on developing individuals' ability and promoting learning transfer, often with durations of a few semesters. In sum, if educators seek to guide participants to consider the elements of arts/esthetics or important issues and values in specific social context, or to stimulate their creativity, then the arts could be used to deepen STEM knowledge and improve individuals' abilities.

However, the roles of the arts are controversial (Colucci-Gray et al., 2017; Perignat & Katz-Buonincontro, 2019). Perignat and Katz-Buonincontro (2019) examined 44 published articles and found most studies defined the "A" in STEAM as arts education (e.g., visual or performing arts), some as non-STEM disciplines (e.g., liberal arts and humanities), and others lacked any definition of "A" or defined it as a synonym for project-based or technology-based activities. Among these studies, Clapp and Jimenez (2016) adopted a comprehensive view that the "A" in STEAM should be arts as a discipline, esthetics, and creativity. However, two of the roles of A—arts disciplines and esthetics—might overlap in meaning. For instance, an activity incorporating new media would be difficult to categorize as involving both visual art and theater, and as promoting the consideration of making a work appealing to the senses. Furthermore, other studies have also highlighted the arts' relation to esthetic education (May & Clapp, 2017; Smith, 2004). Thus, we defined arts/esthetic learning as the first role of A. Its definition is practices that involve art disciplines (e.g., visual arts, music, theater), key artistic concepts (e.g., abstraction, composition, improvisation), or a consideration of esthetic literacy (e.g., appealing to the sensory experience of a product). It is closely related to discipline-based art education (Eisner, 1987); which incorporated a huge set of art disciplines (i.e., art making, art criticism, art history, and esthetics), and whose effect has been confirmed (Tapajos, 2003). In general, the arts/esthetic learning opens up a new perspective of how the physical world works. The process whereby Niels Bohr constructed his model of atomic structure in 1913 could be an example. It has been argued that Bohr was influenced by contemporary literature and arts (e.g., Cubism) and proposed a new way to conceptualize atoms (Clarke, 2014). His model laid the foundation for the development of quantum physics.

The second role of the arts should be contextual understanding. Its definition is practices that promote the reflection of others' life situations or the sociocultural context. This role was stated by Yakman

(2010, 2012), the founder of STEAM education. She suggested that the arts could expand the traditional STEM fields to reflect society's values and directions in the past and present, thus confirming the values of contextual understanding. The meaning of contextual understanding is relatively similar to human-centered design, which emphasized on making sense of the technology by exploring the interconnected sociotechnical world and asked questions such as, "How can we effectively support individuals while simultaneously changing big systems?" (Boy, 2013; Brown, n.d.). The National Research Council ([NRC], 2013) suggested that a holistic understanding of the nature of science consists of an understanding that many decisions not only rely on scientific knowledge but are shaped by their social and cultural context. Previous researchers have proposed that literacy should be valued equally as science by permitting the majority of the public to understand the implications as they read literature, philosophy, history, and poetry conveying artists' critical thinking and humanistic concern (Osborne, 2002; Snow, 1959). To take this a step further, Perignat and Katz-Buonincontro (2019) suggested that it is essential to incorporate the hallmark elements of arts education, including critique, self-expression, and conveying meaning, to enhance STEAM activities. It indicated that if we include the element of contextual understanding in scientific courses, individuals' understanding of the sociocultural dynamic could be deepened, scientific data could be more meaningfully interpreted (Harris, 2010), more critical social issues could be emphasized (Chu et al., 2019; Gaztambide-Fernández, 2013), and more creative moments could be generated (Snow, 1959). For example, Herro and Quigley (2017) adopted the concept of contextual understanding in their STEAM study. They asked participants to provide solutions for residents who lived near a local river that government officials would like to use to harvest renewable energy. Besides STEM knowledge, the participants must consider the "A," including not only political, social, economic, environmental, and historical context of the local river, but the human dimensions of esthetic design for the park environments. In general, the element of contextual understanding indicated that contemporary science education should be preprofessional preparation for not only elite scientists and technologists, but also for citizens who can understand the cultural norms and values behind the context (e.g., the cultural hegemony of science in Western societies) and generate critical and evaluative interpretations.

The third role of the arts is creativity, as Clapp and Jimenez (2016) suggested. Most researchers adopted the definition of creativity that it must be both novel and useful (Runco & Jaeger, 2012), although some of them packed the two criteria in an implicit way or proposed the third criterion. For the former, Bruner (1962) proposed the "effective surprise" by substituting the criterion novel for surprise. For the latter, Simonton (2018) proposed criterion surprise, which represented the potential of the work to evoke a response of "wow," but it was highly correlated with the criterion novel (e.g., Glăveanu et al., 2019). Thus, this study adopted the oft-cited criteria of novel and useful for creativity, on which a consensus has been reached. Furthermore, similar to Clapp and Jimenez, we take a domain-specific perspective since the creativity mentioned here should emerge in certain domains of practice. Here, the definition of creativity here is practices that assist individuals in making creative products that are novel and useful in a domain-specific context. The creativity in this study could be classified into little-c creativity (i.e., the creativity in the everyday settings) or minic creativity, which involved the personally meaningful understanding and interpretation of experiences, according to Kaufman and Beghetto's (2009) Four C model. Creativity might be fostered in individuals through STEAM activities, with the perspective that the STEAM approach is designed to provoke participants' interest by offering opportunities to learn STEM knowledge in more creative and playful ways (Chu et al., 2019). As the most important ability for competition in a fierce global economy and the search for new solutions (Kim et al., 2016), creativity is traditionally associated with the arts and humanities. Thuneberg et al. (2018) proposed an integration of creativity, which they summarized in the arts, to introduce new impulses into STEM education, leading to better acceptance and innovation in science by students. To summarize, we define three codes for the A in STEAM: A1 = arts/esthetic learning, A2 = contextual understanding, and A3 = creativity and the other codes (see Table 1).

To illustrate the idea of the three arts roles, let us take a survival horror adventure video game created by a Taiwanese game developer as an example. The video game *Detention* is a 2D atmospheric horror side-scroller. It won the Journey Award at IndieCade

Table 1
Codes and Definition of the STEAM Acronym

Topic area	Code	Definition
Science	S	Involving science disciplines including the physical sciences (e.g., biology, chemistry, physics) and social sciences (e.g., sociology, psychology), or reference to key scientific concepts (e.g., matter, energy).
Technology	T	Involving technology-based disciplines (e.g., computer and information technology, informatics) or the modifications of the related byproduct.
Engineering	E	Involving design-based objects, processes, and systems within engineering disciplines (e.g., aeronautical engineering, chemical engineering).
Mathematics	M	Involving disciplines of mathematics (e.g., trigonometry, algebra, calculus) or key mathematical concepts (e.g., spatial reasoning, data analysis).
Arts/esthetic learning	A1	Involving art disciplines (e.g., visual arts, music, theater), key artistic concepts (e.g., abstraction, composition, improvisation), or a consideration of esthetic literacy (e.g., appealing to the sensory experience of a product).
Contextual understanding	A2	Involving practices that promote the reflection of others' life situations or the sociocultural context.
Creativity	A3	Involving practices that assist individuals in making creative products that are novel and useful in a domain-specific context.

2017 and has received favorable reviews from critics since its release in 2017. The idea of this game was influenced by the English novelist George Orwell's *Animal Farm* (Orwell, 1945). In *Detention*, the production team preserved the historical memory of Taiwan during the White Terror Period, showing the bloody roots of a country oppressed by martial law for over 38 years. For the arts/esthetic learning, music serves as a major part of the narrative, with the composer fuzing elements such as Electronic, Lo-Fi, and Rock with traditional Taiwanese instruments to create a tense and thick atmosphere. Through contextual understanding, players would understand the suffering of people struggling to live in an oppressed world while engaging in this thought-provoking game, and in turn learn to tell a meaningful and painful story that belongs to us all. For creativity, players could imagine the development of the creepy adventure along with auditory cues and clever puzzles. More interestingly, there are alternate endings in this game, allowing the player to arrive at a slightly more personal finale based on their own choices. Thus, we found this game to be a good example of applying the three arts as a core focus.

In Taiwan, many STEAM activities have been on the rise since the first issue of *Make: Taiwan* magazine was published in 2011, but to what degree do these learning experiences engage individuals in the arts instead of simply decorating a sophisticated STEM project with stickers? Thus, one critical question that guided our research was, What is the quality of each topic area associated with the STEAM acronym, especially the three roles for A, in STEAM-related activities in Taiwan? The quality of certain topic area was examined based on the depth of certain knowledge required of authors to develop the activities. Another critical question was whether each of the three art roles conveys its uniqueness.

Methodological Approach

This study has received ethics approval from the Research Ethics Committee, National Taiwan Normal University (201907HM003). This study adopted a conversion mixed design (Teddlie & Tashakkori, 2009), which was also called the data-transformation triangulation design (Creswell & Plano Clark, 2007). During this study, we first collected and analyzed the qualitative data and then converted it into quantitative scores for analysis. For the qualitative data, the STEAM-related activities in Taiwan were collected and examined. For the quantitative data, we applied Amabile's consensual assessment technique (CAT; Amabile, 1983) to quantify the quality of the STEAM acronym in this limited data sample. Finally, both types of data were compared and integrated, which could strength and enrich our findings. The details are provided in the following paragraphs.

First, because we suggest that the goals of a product and a curricular activity show a discrepancy (see the Background section), the two kinds of activities were defined operationally by their data sources and examined separately. Three broadly accessible data sources were collected (please see the Appendix): (a) 37 "products" from the total forty issues of *Make: Taiwan* magazines provided by Taiwan's makers, (b) 13 "curricula" acquired by surveying databases with keyword as STEAM learning whose authors were Taiwanese, and (c) 12 awarded "curricula" from a maker and tech center founded by the Ministry of Education in Taiwan. Thus, the full data set included a total of 62 activities, including 37 products and 25 curricula. Regarding the demographics of these activities' first authors, all of them were Taiwanese (eight women). Science/engineering majors (n = 23; 22 males, one females) consisted of those who were majoring in the subject (such as animal science, computer science, and engineering). Double majors (n = 15; 15 males, zero females) consisted of those who were majoring in two different subjects (such as technology and human resource development). Education majors (n = 13; 10 males, three females) consisted of those who were majoring in the subject (such as education and science education). Arts/humanities majors (n = 11; seven males, four females) consisted of those who were majoring in the subject (such as animation and visual arts).

Second, Amabile's CAT (Amabile, 1983) was applied to assess the quality of STEAM acronym in this data sample. After proposing a preliminary coding scheme, three experts engaged in a formative coding process to test the usability of the codes and examine the quality of all activities. We found that certain topic areas in an activity might be of higher quality. Authors required deeper knowledge in that topic area for designing the activity. However, certain other topic areas in an activity might be of lower quality, demanding authors only limited and/or superficial applications of the concepts related to the topic area when developing the activity. Thus, the scores were weighted accordingly (higher quality = 2, lower quality = 1, null = 0). For example, in the House Plant Generator in *Make: Taiwan*, the author encouraged readers to test whether LED strip lights could work by placing copper and zinc sheets into wet mud or brine, a mixture of salt and water. Through the activity, the author addressed the deeper scientific knowledge behind the activity by explaining that the brightness of the light would be influenced by the properties of soil (e.g., its electrolytes), the sizes of sheet metal, and the distance between them. In another *Make: Taiwan* activity, Haunted Phone, the author mentioned that the current for ringing a phone is only 20 V at a frequency of 20 Hz, which is different from the AC used at home, and clearly explained how to replace it with an alarm clock. In this activity, the deeper scientific knowledge was not addressed extensively. Thus, the House Plant Generator was coded science/higher quality = 2, whereas Haunted Phone was coded science/lower quality = 1. To be consistent with the CAT methodology, the raters were asked to rate all activities independently. The researchers participated as raters in STEM/STEAM-learning-related projects and/or has academic publications related to STEM/STEAM learning. Two raters' background were industrial education and computer-aided design, which were domain-specific experts in creativity. Another rater specialized in educational psychology and has research interests in innovative instruction and creativity for over a decade. To estimate interrater reliability, we adopted the intraclass correlation coefficient (ICC), which has been recommended as the best quantified method for continuous rating scales (Hoyt, 2010). The model assumed that one set of raters examined all activities in the data set (two-way random effects; Shrout & Fleiss, 1979). Following Montgomery et al. (2002), we used the standard values for interpreting the ICC (ICC = .41–.60 represents "moderate agreement"; .61–.80 "substantial agreement"; >.80 "almost perfect agreement"). As shown in Table 2, the interrater reliabilities (ICC) of science, technology, engineering, mathematics, art, arts/esthetic learning, contextual understanding, and creativity ranged from .65 to .90, demonstrating substantial to almost perfect agreement.

After calculating the average scores in every topic area, we conducted "repeated-measures analyses of variance" with SPSS

Table 2

The Means and Standard Deviations of Quality Scores on Topic Areas Enacted Within Activity Types/Author Amounts and the ICC of Each Topic Area

	Activity type		Author amount		Total	
Topic area (code)	Product *M* (*SD*)	Curricula *M* (*SD*)	Individual *M* (*SD*)	Team *M* (*SD*)	*M* (*SE*)	ICC
Science (S)	0.95 (0.61)	1.25 (0.73)	0.98 (0.68)	1.19 (0.67)	1.10 (0.09)	.85
Technology (T)	1.10 (0.84)	1.68 (0.45)	1.07 (0.85)	1.69 (0.41)	1.39 (0.09)	.90
Engineering (E)	1.00 (0.72)	1.55 (0.45)	1.03 (0.70)	1.47 (0.55)	1.27 (0.08)	.85
Mathematics (M)	0.87 (0.52)	1.16 (0.43)	0.88 (0.53)	1.14 (0.43)	1.02 (0.06)	.70
Arta (A)	0.77 (0.36)	1.28 (0.44)	0.85 (0.38)	1.16 (0.52)	1.03 (0.05)	.75
Arts/esthetic learning (A1)	0.94 (0.60)	1.19 (0.70)	1.06 (0.58)	1.01 (0.75)	1.06 (0.08)	.84
Contextual understanding (A2)	0.49 (0.40)	1.07 (0.58)	0.51 (0.40)	1.01 (0.62)	0.78 (0.06)	.65
Creativity (A3)	0.89 (0.53)	1.60 (0.42)	0.98 (0.56)	1.45 (0.55)	1.25 (0.06)	.74

Note. The possible quality scores for each topic area ranged from 0 to 2. ICC = intraclass correlation coefficient.
[a] The score for art was calculated by averaging the scores of arts/esthetic learning, contextual understanding, and creativity.

statistics software (Version 23). We adopted the activity type as the between-subjects variable and the topic area as the within-subject variable to examine the main effects of each variable and their interaction effects on quality scores. Furthermore, a correlation analysis was also performed to examine the relationships between the three art roles.

Results

The STEAM Scores in Activities

The score for art was calculated by averaging the scores of A1, A2, and A3. A 2 × 5 (Activity Type × Topic Area) analysis of variance (ANOVA) test on the average quality scores was conducted (see Table 2). The main effect was significant on activity type, $F(1, 60) = 18.57$, $p < .001$, $\eta_p^2 = .24$, and significant on topic area, $F(4, 240) = 6.92$, $p < .001$, $\eta_p^2 = .10$, but there was no significant interaction effect, $F(4, 240) = 1.27$, $p = .286$. For the activity type, post hoc comparison indicated that the curricula had significantly greater scores than the products, indicating that the curricula provided more integrated and transdisciplinary learning than the products. For the topic area, the score for technology was significantly higher than those for science, mathematics, and art, and the score for engineering was significantly higher than for mathematics and art.

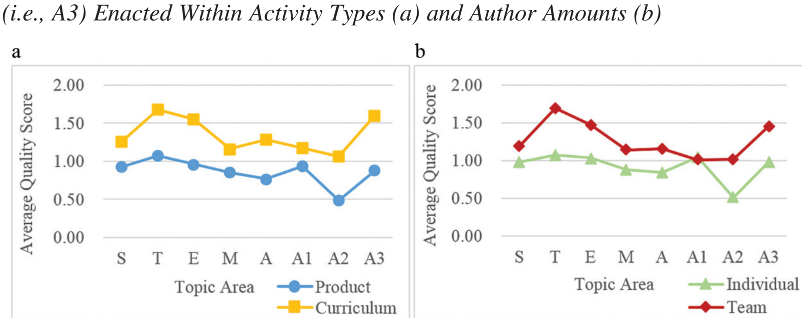
A 2 × 7 (Activity Type × Topic Area) ANOVA test on the experts' average scores was also conducted (Figure 1a). The main effect was significant on activity type, $F(1, 60) = 27.16$, $p < .001$, $\eta_p^2 = .31$, and significant on topic area, $F(6, 360) = 8.95$, $p < .001$, $\eta_p^2 = .13$, with no interaction effect, $F(6, 360) = 1.80$, $p = .137$. For the activity type, post hoc comparison indicated that the curricula had significantly greater scores than the products. For the topic area, the score for technology was significantly higher than for science, mathematics, A1, and A2, the score for A3 was significantly higher than for mathematics, A1, and A2, and the score for engineering was significantly higher than for mathematics and A2. In addition, the score of A2 was significantly lower than for any other topic area.

The STEAM Scores in Groups

As just mentioned, the scores for curricula were significantly higher than the scores for products. We suggest that this might reflect the numbers of the authors that developed these activities, because the demographic data showed that most product activities were developed by individual makers, although most curricular activities were created by teams. The collaboration between authors might have effects on the quality of a STEAM activity. Previous studies have confirmed that through collaboration, a multidisciplinary team is often capable of applying and combining

Figure 1

Average Quality Scores of Science, Technology, Engineering, Mathematics, Arts/Esthetic Learning (i.e., A1), Contextual Understanding (i.e., A2), and Creativity (i.e., A3) Enacted Within Activity Types (a) and Author Amounts (b)



Note. See the online article for the color version of this figure.

each unique expertise of the members to achieve optimal performance (e.g., Schmutz et al., 2019). To examine whether a team could develop/design STEAM activities with better qualities than an individual, we identified each activity's author numbers from their demographic data, and thus two author amounts emerged: individual author (n = 36) and team author (n = 26), and then a 2 × 5 (Author Amount × Topic Area) ANOVA on the average quality scores was conducted. As shown in Table 2, the team author performed significantly better than the individual author, $F(1, 60) = 11.57$, $p = .001$, $\eta_p^2 = .16$. There was also a significant effect of topic area, $F(4, 240) = 7.29$, $p < .001$, $\eta_p^2 = .11$, but no interaction effect, $F(4, 240) = 1.79$, $p = .150$.

A 2 × 7 (Author Amount × Topic Area) ANOVA test on the average quality scores also found a significant effect for author amount, $F(1, 60) = 13.07$, $p = .001$, $\eta_p^2 = .18$, and a significant effect for topic area, $F(6, 360) = 9.23$, $p < .001$, $\eta_p^2 = .13$, as well as a significant interaction effect, $F(6, 360) = 2.84$, $p = .029$, $\eta_p^2 = .05$. A simple main effect analysis was conducted to further understand these relationships. The team author had significantly higher scores than the individual author for technology, engineering, mathematics, contextual understanding, and creativity, $F(1, 60)$ = 11.74, 7.10, 4.25, 15.39, 10.55, p = .001, 010, .044, .000, .002, η_p^2 = .16, .11, .07, .20, .15. The average quality scores across the STEAM areas within the two author amounts are presented on Figure 1b.

The Uniqueness of the Three Art Roles

To understand the uniqueness of the three art roles, Pearson product–moment correlation coefficients were computed. The analysis revealed a medium correlation between creativity and art/esthetic learning (r = .47) and a strong correlation between creativity and contextual understanding (r = .58), but only a small correlation between art/esthetic learning and contextual understanding (r = .12), according to Cohen's (1988) work.

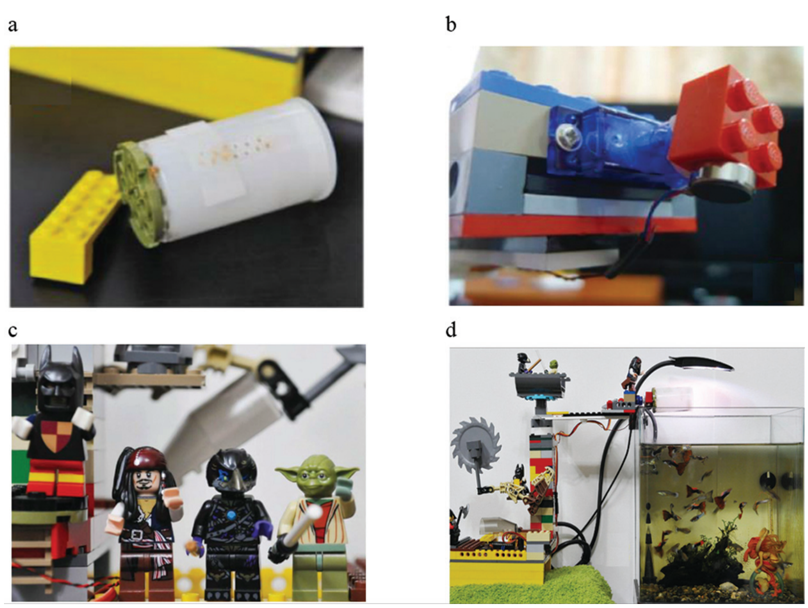
STEM Activities With and Without the Arts

We found some STEAM activities showing the STEM-with-stickers effect or artless STEM effect. One example is a product from *Make* magazine, the Automatic Watch Winder. This activity's total STEM score was above 75% of all activities' scores—6.0 out of 8.0—which was calculated by adding up the quality scores of STEM areas. However, its scores in arts/esthetic learning, contextual understanding, and creativity were only .33, .33, and .00 out of 2.00, which were lower than 75% of all activities. After getting an automatic watch, the author had the idea of making an automatic watch winder to make sure the watch could work precisely. He made a base with a plastic sea-snail-shaped cover often used in monitors and powered it with a portable charger. Later, the author welded on the Arduino Pro mini circuit board and added three LED lighting signals. After programming the Arduino and assembling the automatic winder, the product was complete. Though this activity involved much STEM knowledge, it lacked the implementation of arts/esthetic learning, neglected aspects to provoke thought in the social context, and provided no room for creativity development.

On the other hand, some examples demonstrated the opposite trend—the arts-and-crafts effect (Clapp & Jimenez, 2016);

Figure 2

The Author Created the Feeding Box With a Film Cartridge Box (a) and a Journal Bearing (b), and Incorporated Storyline With Minifigs (c), the Final Work Was Shown as (d)



Note. The activity was "Arduino automatic fish feeder" that designed by Tai-Ying Huang (黃泰穎), 2016, *Make: Taiwan* (Vol. 21, pp. 64–67). Copyright 2016 by Maker Media, Inc. Reprinted with permission. See the online article for the color version of this figure.

indicating that these activities were art-based and art-integrated. Let us take a product from *Make* magazine, Arduino Automatic Fish Feeder (see Figure 2), as an example. Its total STEM score was 6.67, and those for arts/esthetic learning, contextual understanding, and creativity were 1.67, 1.33, and 2.00, respectively, which were all above 75% of all product scores, demonstrating that this activity could be an excellent work. After being asked by a colleague to take care of the fish in his aquarium, the author created this product to satisfy the need to feed the fish three times a day. First, the author produced an Arduino control panel and finished the circuit design, then made a feeding box from a film cartridge box and a journal bearing with a Tower Pro SG 90 mini servo motor (Figure 2a and 2b). This activity deepened makers' understanding of the science, technology, and mathematic concepts. Through the creating process, the author suddenly had the brainstorm of supporting the feeding box with Lego bricks, and he even included several minifigs for an interesting storyline (e.g., he added a bionicle to operate the saw arm; Figure 2c). Finally, the author burned the program into the Arduino control panel, and the fish feeder was completed. Regarding contextual understanding, the author took into consideration the busy and lonely life of modern people, and he created this product for them to take care of their pets. For art/esthetic learning, the author made use of limited Lego bricks to improvise an attractive product with good storyline (e.g., a protective room with Lego bricks). For creativity, for which the author received a full score, he shared the trial-and-error process of using the Lego bricks to build a unique work and encouraged young makers to create their own stories.

Another example of arts-and-crafts effect was a curriculum, "Integration of programming and making: A smart doghouse," as shown in Figure 3. Its total score in STEM was 7.67, which was higher than 75% of all curricula, and the scores for arts/esthetic learning, contextual understanding, and creativity were 1.00, 1.67, and 2.00, showing that it is an excellent work. First, the teachers arouse students' curiosity, interest, and engagement by asking them to consider the issues of stray dogs and how to reuse the abandoned desks and chairs in their school yard, and then expanded the scope of the discussion to the issues of heart rate detectors, automatic feeders, and GPS positioning. The learners were then asked to draw a set of plans for a simple doghouse building. Afterward, the learners strengthened the structure of the doghouse's four pillars with L-shaped angle brackets, pegs, and screws after breaking down the abandoned desks and chairs (Figure 3a). The drinking water storage bucket was used as a container for dog food, the plastic water pipes were used as tracks to transport the food, and the turning degree of the server motor acted as an on-off control to give out food (Figure 3b). Some difficulties (e.g., the torque of the server motor might be overloaded if the dog

Figure 3

Students Tore Down Abandoned Desks and Chairs (a) and Designed the Dog Food Container (b) for the Final Work (c)

a b

c

Note. The activity was "Integration of programming and making: A smart doghouse" that designed by Shih-Feng Tsai (蔡釋鋒), 2017, maker and tech center curriculum (https://tech.nknu.edu.tw/Resource/EduContent/37). Copyright 2014 by Ministry of Education in Taiwan. Reprinted with permission. See the online article for the color version of this figure.

food was too heavy and the flow rate was too high) might be encountered that the learners had to try to solve. Finally, they had to make the server motor work dropping dog food constantly by writing a program.

Taking the stray animals' life education as a topic, the core of the curriculum is the role of contextual understanding whereby makers were invited to examine the relationships between humans, technology, society, and environment. For art/esthetic learning, the learners should understand the differences in paint properties and the way it is applied with a brush, and they then incorporated cultural components of native Taiwanese tribes when coloring the doghouse, as shown in Figure 3c. For creativity, the learners were encouraged to creatively adopt functions of sensors, such as timing lights and an adaptive lighting system based on the distance from an object, or turning on an electric fan once the indoor temperature exceeded 28°F. This activity contained high quality of the arts and activated an in-depth discussion of related STEM concepts as well, thus providing an excellent example.

Discussion and Conclusion

This study examined the quality of 62 STEAM-related products and curricula in Taiwan, with special emphasis on the three roles of the arts. The STEAM scoring trends of products and curricula were similar, though the curricula's total scores were significantly higher than those of the products. Not surprisingly, arts/esthetic learning contained low-quality scores. This unfortunate finding is consistent with those of Clapp and Jimenez (2016) and Yakman (2012) that people are often reminded that what is not basic is ornamental in education, and thus the arts have been neglected in STEM learning in both the United States and Taiwan. We also found that contextual understanding had the lowest score. Integrating the sociocultural values with science learning is emphasized (NRC, 2013; Yakman, 2012); most STEAM activities in Taiwan failed to incorporate deep understanding and reflection on the sociocultural context, and thus were not able to raise truly meaningful questions. Indeed, this is simply unfortunate since art and esthetics cannot be separated from a cultural context, according to cultural anthropologists Peoples and Bailey (2012). By understanding and appreciating the context of systems'/cultures' values and principles, the practical problems in real human communities are more likely be resolved. Furthermore, we found that creativity was strongly implemented, indicating that most activities in our data sample assisted learners with novel and appropriate ways to foster their creativity, such as incorporating creative thinking strategies to transform the teaching environment into a different "play space." Brainstorming is one of the ways that can stimulate learners' creativity as they generate ideas (see Al-Samarraie & Hurmuzan, 2018). Another ways could be creative problem-solving (Parnes, 1967); which has been confirmed as reinforcing the creative skills of various learners (e.g., nursing faculty; Liu et al., 2020).

In addition, we found that mathematics was also insignificant within STEAM learning. This is keeping with Clapp and Jimenez's finding that few activities engaged mathematical content in a meaningful way. Mathematics is essential to almost every discipline. Without a fundamental understanding of mathematics, other disciplines cannot be understood in depth. To address this concern, some studies suggest that deep understanding of mathematical concepts could be promoted by exposing students to handicraft experiences that include arts/esthetic elements (Fenyvesi & Lähdesmäki, 2017; Mack, 2006; Thuneberg et al., 2018). For example, Thuneberg et al. (2018) developed a "math & art" workshop for students to create their own geometrical structure (e.g., machines or mobile equipment) with plastic pipes and circles, and found that the students showed significant improvements on their postknowledge test. Other mathematics educators also advocated forming working groups to "develop a common vision of the role of mathematical content in STEM" (Barakos et al., 2012, p. 5). This indicates that breaking the boundary between disciplines while reinforcing the content of individual disciplines is critical for achieving the STEAM goal.

Another finding of this study is that the team authors designed STEAM activities with significantly higher quality in the areas of technology, engineering, mathematics, contextual understanding, and creativity than did the individual authors, indicating that teamwork in both product and curricular activities increases their quality. Glăveanu et al. (2019) also compared the performances of dyads and individuals; they found that people working together fostered practicality during divergent thinking tasks. Unlike the divergent thinking tests that involved only creative ideation, designing STEAM activities was a domain-specific work and involved creative ideation, interpretation, and expression. Hence, we speculated that practicality should be a prerequisite to design a STEAM activity; thus, both groups and individuals would be able to propose practical works. The advantage held by groups appeared in the quality of STEAM activities designed by them. To develop a product activity with high quality, makers must create their works by sharing resources and knowledge with team members, working on projects, and solving problems, showing that making culture involves both do-it-yourself (DIY) and do-it-with-others (DIWO) techniques (Karppinen et al., 2019; Rosenfeld-Harverson & Sheridan, 2014). Similarly, to develop an excellent curricular activity, teachers of various disciplines must collaborate as a team to create transdisciplinary curricula (Herro & Quigley, 2017; Liao, 2019). Take Herro and Quigley's (2017) study for example: They asked middle school teachers to develop STEAM courses together and found that most teachers proposed collaboration as an initial step to generate transdisciplinary teaching, because they could be forced to identify the content expertise outside their specific disciplines and think beyond their content areas. Thus, collaboration might be a good way to induce different points of view and incorporate more ideas into one's project, thereby generating STEAM activities that activated all topic areas.

Regarding the uniqueness of the three art roles, they were related but all three reflected their uniqueness. We found a medium correlation between creativity and art/esthetic learning and a strong correlation between creativity and contextual understanding. This finding is opposed to Clapp and Jimenez's (2016) study but similar to previous research findings that incorporating the arts within STEM activities is a means to uncover individuals' creative potentials (Liao, 2016; Sousa & Pilecki, 2013). Snow (1959) also proposed that as the humanities or arts and the sciences are integrated, the most creative moments would emerge. In addition, we also noted that there was no correlation between art/esthetic learning and contextual understanding. This lack of correlation contradicts the perspective of cultural anthropology that art/esthetic should be inseparable from the cultural context (Peoples & Bailey, 2012). One possible explanation for this is that most authors that designed STEAM activities in Taiwan held an incomplete understanding of the art meanings in STEAM, thus often incorporating limited art elements in their activities—either the learning of art disciplines or the understanding of practical social issues.

Unlike the findings of Clapp and Jimenez (2016), the contextual understanding was included in the role of the arts. Since Yakman (2010) has called for constructing scientific learning in a holistic sociocultural model, many researchers have emphasized the importance of advanced scientific understanding in a personal, meaningful, and social context (Boy, 2013; Chu et al., 2019; NRC, 2013; Osborne, 2002; Yakman, 2012). As proposed by Boy (2013), we must acquire not only the tools and techniques, but also the ability of understanding complex systems, expressing, critiquing, and exploring possible futures—which is the essence of human-centered design, to live in this constantly evolving sociotechnical world. With this STEAM approach, which involved both contextual understanding and STEM content, more local problems and contemporary social issues could be studied. For example, Braund and Reiss (2019) suggested developing science curricula in science-technology-society contexts, which should be a way to improve the teaching and learning of science by applying the arts. Taking this idea a step further, involving learners in the contexts of different cultures could deepen their understanding of a given scientific conception. Chu et al. (2019) developed an intercultural STEAM program by integrating the arts and sociocultural components in scientific learning. Students from Australia and Korea had opportunities to explore natural phenomena while considering the effect of the sociocultural context (e.g., the Earth's tilted axis manifested as various seasons in different hemispheres), and finally they showed that they had acquired constructed science knowledge at the end of these lessons.

In addition, the data pool in Clapp and Jimenez's (2016) study concerns maker-centered activities, and they found that these activities are not inherently artful. In this study, the data pool was expanded to incorporate STEAM-related curricula, with the inclusion criterion that the term *STEAM learning* was referenced. However, we still found that the arts were only loosely involved in these activities, indicating that arts learning is not inherent even in activities that claim to teach STEAM disciplines. Herro and Quigley (2017) found that most teachers understood the necessity of STEAM, but they were not clear about approaches to STEAM teaching. To facilitate STEAM education, it is essential to move from the traditional army model to the Orchestra Model, that is, from pyramidal structure to networked functions, as suggested by Boy (2013). The educators should be provided greater autonomy and opportunities to develop STEAM-related curricula corporately and coordinately (e.g., establish a daily planning time together), participate in productive professional development, and consult with educational experts.

Some directions for future research could be considered. First, this study examined the quality of individual topic areas and the roles of the arts in Taiwan's STEAM-related activities. Future studies should extract critical principles for enhancing the arts roles in these STEAM activities to foster more comprehensive skills of learners. Second, we incidentally found that team authors produced STEAM activities with significantly better quality than did individual authors. For future studies, researchers could develop experiments to clarify the performances between individuals and teams or to further investigate the performances between teams with similar or varied background specializations in designing STEAM-related activities.

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(*Appendix follows*)

Appendix

Table A1
The STEAM-Related Activities Used in This Study

No.	Activity	Author amount	Title	Average quality score S	T	E	M	A1	A2	A3
1	Product	1	Little Monster	1.33	2.00	1.50	1.33	0.33	1.00	1.33
2	Product	1	Jet Stream Power Blaster	1.00	1.00	1.33	0.67	0.33	0.67	0.33
3	Product	1	C5 Launcher	1.67	0.33	1.33	0.67	0.33	1.00	0.67
4	Product	1	Colorful LED Bulbs With a Sound Detection Sensor	1.00	2.00	1.00	1.67	2.00	0.67	1.33
5	Product	2	Magic Jewelry Game with RGB LED matrix panels	0.33	2.00	1.33	1.33	0.33	0.33	1.33
6	Product	1	Tiny Interactive Showcase	1.67	2.00	1.00	1.33	1.00	0.67	1.00
7	Product	1	Action figure Danboard	1.00	2.00	2.00	1.67	1.00	0.33	1.67
8	Product	1	A Living Action Figure–Hatsune Miku	0.67	2.00	1.67	1.67	1.00	0.33	1.00
9	Product	4	Dragonfly	1.33	2.00	2.00	1.00	0.00	1.67	1.00
10	Product	1	Jet Stream Power Blaster M-Strike	2.00	0.33	1.00	1.00	1.00	0.00	0.67
11	Product	1	House Plant Generator	2.00	1.33	1.33	1.33	1.33	1.00	1.67
12	Product	1	Orange Flavored Coconut Oil Dish Soap	2.00	0.00	0.67	1.00	1.00	0.33	0.33
13	Product	1	Modeling Making of Cockroach	0.33	0.00	0.33	0.33	2.00	0.33	1.67
14	Product	1	Star-Light Hair Band	1.00	1.33	0.00	1.00	1.67	0.67	1.67
15	Product	1	Modeling Making of Kamen Rider	0.00	0.00	0.67	0.00	1.67	0.00	1.33
16	Product	1	Modeling Making of Mecha Godzilla	0.33	0.00	0.00	1.33	2.00	0.67	0.67
17	Product	1	Arduino Automatic Fish Feeder	1.00	2.00	2.00	1.67	1.67	1.33	2.00
18	Product	7	Haunted Phone	1.00	2.00	0.67	1.00	0.33	0.00	0.33
19	Product	1	Make a Desktop Audio System	1.33	1.67	1.67	0.67	0.67	0.67	1.33
20	Product	1	Automatic Watch Winder	1.00	2.00	2.00	1.00	0.33	0.33	0.00
21	Product	1	DIY Angemon Model	0.33	0.00	0.33	0.67	1.67	0.00	0.67
22	Product	1	Dual Extruder 3D Printer	0.00	2.00	2.00	1.33	0.00	0.00	0.67
23	Product	1	Electronic Magnifier	1.00	1.33	0.33	0.00	0.00	0.67	0.67
24	Product	2	Lighted Wine Bottle	0.00	1.00	0.00	0.33	1.00	0.67	0.33
25	Product	1	Snowman Season	0.00	0.00	0.00	0.33	1.33	0.00	0.67
26	Product	1	Portable Reading Bookshelf	0.33	0.00	0.67	0.33	0.67	0.33	0.33
27	Product	1	DIY Hand Spinner	1.33	1.33	1.33	1.00	1.00	0.33	1.33
28	Product	1	Chocolate Casting	1.00	1.00	0.67	0.33	1.33	0.33	0.33
29	Product	1	Winogradsky Column	2.00	0.67	0.00	0.33	0.00	0.67	0.67
30	Product	1	Papier Mâché	0.67	0.00	0.00	0.00	1.00	0.67	0.33
31	Product	1	Tree Ring Stamp	0.00	0.00	0.00	0.00	1.33	0.00	0.33
32	Product	1	Dandelion in Resin Specimen	1.00	0.00	1.00	0.67	1.00	0.00	0.67
33	Product	1	Frog Skeleton in Shrink Plastic	1.33	0.33	0.33	0.33	1.00	0.00	0.33
34	Product	1	Raspberry Pi Weather Dashboard	0.67	2.00	2.00	1.33	0.33	0.67	0.67
35	Product	1	Projection Lamp for Halloween	0.67	2.00	1.00	1.00	1.33	0.67	1.00
36	Product	6	School Carnival Arcade Machine	1.00	1.67	1.67	1.33	0.33	0.33	0.67
37	Product	2	Bionic Beast	1.67	1.33	2.00	1.33	1.33	0.67	2.00
38	Curriculum	8	IoT Assistant Devices for the Elderly	1.67	2.00	2.00	1.00	1.33	2.00	2.00
39	Curriculum	3	Human-Computer Interaction System Design	1.00	2.00	1.67	1.33	0.00	1.33	1.67
40	Curriculum	5	3D-Printing/Handmade CO2-Car	2.00	2.00	2.00	1.67	2.00	1.00	2.00
41	Curriculum	4	CO2 Racing Car	2.00	2.00	2.00	1.67	2.00	1.00	2.00
42	Curriculum	3	Green Building with Sensor Controls	2.00	2.00	2.00	2.00	2.00	1.67	2.00
43	Curriculum	3	Historic Sites and Cultural Preservation Courses	0.33	1.67	0.33	0.00	2.00	2.00	2.00
44	Curriculum	1	Passive Phone Speaker	2.00	2.00	2.00	1.00	1.67	0.67	2.00
45	Curriculum	1	Rubber Band Car	1.67	0.67	1.67	1.00	1.00	0.67	1.67
46	Curriculum	7	Dynamic Piggy Bank	1.00	1.67	1.33	0.67	1.00	0.33	1.33
47	Curriculum	7	3D-Pring Doll	1.00	2.00	1.67	1.00	1.33	1.00	1.33
48	Curriculum	7	Creative Night Light Lamp	0.00	2.00	1.33	1.33	2.00	0.67	2.00
49	Curriculum	2	Creative Quadrotor	0.67	2.00	2.00	1.33	0.00	0.33	1.33
50	Curriculum	2	Solar Cooker Curriculum	1.67	0.67	1.33	0.67	0.67	1.33	1.00
51	Curriculum	2	Wind Turbine	2.00	1.67	1.67	1.33	0.67	1.67	1.33
52	Curriculum	2	Electronic Scroll with Micro: Bit	1.00	1.67	1.00	1.33	0.00	0.67	1.33
53	Curriculum	2	Pottery Clock	1.33	2.00	1.00	1.33	2.00	1.33	2.00
54	Curriculum	2	Train Your Computational thinking: A Cellphone Stand	0.00	1.00	1.33	0.67	1.33	0.67	1.00
55	Curriculum	3	Kitchen Waste Processing Machine	1.67	1.33	2.00	1.00	1.33	1.67	2.00
56	Curriculum	2	Acquire STEAM Ability From a Wooden Whistle	1.33	1.00	1.33	1.00	1.67	1.67	1.67

Table A1 (*continued*)

No.	Activity	Author amount	Title	Average quality score						
				S	T	E	M	A1	A2	A3
57	Curriculum	1	Integration of programming and making: A smart doghouse	2.00	2.00	2.00	1.67	1.00	1.67	2.00
58	Curriculum	3	Be a 3D Maker	1.00	2.00	1.00	1.00	0.33	0.00	0.67
59	Curriculum	3	Alter System for monitoring Water Level	2.00	2.00	1.67	1.67	0.00	1.67	1.33
60	Curriculum	1	Design Your Class Sign	0.00	2.00	1.00	0.67	1.33	0.67	1.00
61	Curriculum	1	Shiny Animal-Shaped Lamp Holder	0.00	1.33	1.33	1.33	1.67	0.33	1.33
62	Curriculum	3	Maker's Catapult	2.00	1.33	2.00	1.33	1.33	0.67	2.00

Note. The possible quality scores for each topic area ranged from 0 to 2. ICC = intraclass correlation coefficient.
[a] The score for art was calculated by averaging the scores of arts/esthetic learning, contextual understanding, and creativity.

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