Developing STEAM educators' proficiency scoring framework

Caesar P. Palisoc[1,*], Marie Paz E. Morales[1], Ruel A. Avilla[2], Thaddeus Owen Ayuste[2], Benilda Ramos-Butron[2] and Nica A. Casilla[3]
[1]Graduate Teacher Education Faculty, College of Graduate Studies and Teacher Education Research, Philippine Normal University Manila 1000, Philippines
[2]Faculty of Science, Technology and Mathematics, College of Teacher Development, Philippine Normal University Manila 1000, Philippines
[3]Publication Office, Philippine Normal University Manila 1000, Philippines
[*]Correspondence: palisoc.cp@pnu.edu.ph
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ABSTRACT

The study aimed to develop the scoring framework for the self-rating proficiency indicators for Philippine STEAM educators. The study further sought to design mathematical framework and program for scoring STEAM educators' proficiency and validate the designed scoring program. About 1507 responses from the self-rating STEAM proficiency tool were used to undergo the three tier quantitative and qualitative validation. Mathematical equations were derived to direct the development of the scoring programs using Microsoft Excel and Fortran. Results show an agreement between the proficiency profiles generated from the Microsoft Excel and Fortran program. Using the online survey and the classroom observation rating, proficiencies were compared as determined through the Fortran program of the pre-determined career stage (distinguished, highly proficient, proficient, beginner). Lastly, qualitative validation was performed by comparing the generated codes in the interview transcripts and observation notes and the attributes in the PPST domains and TPACK dimensions. Qualitative validation indicates that the occurrences of the indicators in the interview and classroom observation matched with the expected attributes per career stage as per the PPST. This indicates that the validation of the scoring system developed for the online survey generate the STEAM educator proficiency. Further, the scope of the scoring framework developed is universal and may be adapted to suit any local setting. However, increasing the number of interviews and classroom observations to 10% of the sample population of teachers will produce a robust scoring program.

Keywords: STEAM education, TPACK dimension, PPST domain, STEAM educators' proficiency, STEAM proficiency scoring program

INTRODUCTION

Education seems to be the basis of every country's progress and groundwork for its future. This tagline exists for many generations taking a new form from one era after another. The entire timeline notes three major education themes that directly influence the society: Education 1.0 underscored agriculture education for agriculture industry, Education 2.0 responded to industrial society, and Education 3.0 addressed the technology society (Diwan 2017). Currently, the quest for industrial revolution 4.0 (IR 4.0), dominated by global connectivity, smart machines and new media, dictates the new contour of education to foresee training and re- and upskilling of the future workforce of this era (Haron 2018). Education in this digital era known as Education 4.0 (E 4.0) and labeled as the "Dawn of Digital Monarchy" envisions to facilitate educating the Generation Z (13-19 years old) learners to imbibe life skills and skills of creating innovation to develop the future workforce 4.0 who exhibits the 4Is: intelligent, interconnected, instrumented, and innovative (Goldsberry 2018) with a "learning is a way of life" mindset (Shook and Knickrehm 2017). This education framework emphasizes a new vision for learning where content and subject matter are secondary to the knowledge of why you need something, and where to find it (Fisk 2017). It features learning together and peer learning where teachers primarily act as facilitators of the learning mechanism dictated by the learners, and machines aid the facilitators in tracking the learners' performance through data-based customization. This schema especially applies to STEM education, which later was known as STEAM (Ghanbari 2015) or Science, Technology, Engineering, Agri/Fisheries and Mathematics education in an effort to integrate design and creativity, - one of the most sought-after main pillars of knowledge-based society and economy (Ministry of Finance of the Slovak Republic 2018). While E 4.0 frames the new learning paradigm for workforce 4.0, the new education framework calls for quality, re and upskilled teachers to catalyze learning in IR 4.0.

Quality and re and upskilled teachers direct STEM/STEAM education to quality, which can prepare the future workforce with skills that match the new skill demands of IR 4.0 (Deloitte 2015). Furthermore, they need to facilitate STEAM learning for the Generation Z learners to acquire a strong background on the meta-discipline (Morrison 2006; Tsupros et al. 2009; Ejiwale 2013), and to obtain specific and highly intricate skills such as design thinking, time management and programming skills (Montero and Evans 2011; Mars et al. 2016) aside from life skills and the 4Is. STEAM educators perpetuate learning as a way of life for the Generation Z learners to survive and be successful in their future work environment (Renjen 2018).

The demand for quality STEAM education to be in the loop of Education 4.0 framework forges the need for re and upskilled competencies of STEAM teacher quality. As Wilson (2016) claimed, teaching in this era should go beyond the teaching of disciplinary subject matter, instead, teachers should focus on the integrative presentation of lesson to learners, e.g. authentic/problem-based learning and design thinking, emphasizing interdisciplinary approach using STEAM field to teach a STEAM course.

Feedback system and assessment should emphasize formative development of students' skills to demonstrate their learning and its relevance to society (Miller 2017). Finally, quality STEAM teachers should showcase dynamic professional development as pathways to success (e.g. collaborative/partnerships, community service for service learning, and professional learning). These traits feature the new skills of quality STEAM teachers who are driven by what they know and what they can do with what they know (Obama 2016) to train our Generation Z learners to learn the trick of how to solve real problems and be contributory to the society.

There are already numerous efforts to provide quality education by improving the quality of teachers. Training and upskilling of teachers in other countries commenced to attain the aforementioned traits and new skill set required to be quality STEAM teachers of the Generation Z learners which calls for monitoring and assessment tools. In fact, the National Research Council proposed two indicators for STEM teacher quality: teachers' science and content knowledge for teaching and teachers' participation in STEM-specific professional development. Similar efforts surfaced in the STEAM world (Kim and Kim 2016) extending the attempt from identifying and polishing the new teacher quality competencies to developing STEAM quality teaching indicators and rating tools.

In the Philippines, standards for professional teachers Philippine Professional Standards for Teachers (PPST) set the tone of research activities related to teacher quality (Department of Education-Teacher Education Council 2017). Specifically, PPST outlines the desired competencies and skills of quality teachers to enable them to handle and manage emerging global frameworks. However, PPST targets the primary, junior, and senior education level with no existing elaborations on subject matter or content, and teaching and learning of complex skills in the tertiary level, thus, enjoining the group of Morales et al. (2019) to design a self-rating proficiency indicator for tertiary STEAM (with "A" for Agri/Fisheries) teachers framed from the paradigms of PPST; Policies, Standards and Guidelines of the Philippine Commission on Higher Education (PCHED); and the theoretical underpinnings of Technological Pedagogical Content Knowledge (TPACK) (Mishra and Koehler 2006). This self-rating tool boosts the disciplinal mapping and matching of the seven domains of PPST and the seven TPACK dimensions to capture the entire spectrum of competencies expected of a Philippine tertiary STEAM quality teacher. Apparently, Kim and Kim (2016) tracked similar path specifying constructs and domains to which teacher quality may be gauged through a self-rating tool (Kim and Kim 2016). However, minority among the identified studies in an exhaustive literature search present the assessment framework of the developed self-rating tool, thus the current investigation focuses on developing the corresponding assessment framework for the self-rating proficiency indicators for Philippine STEAM educators that highlights the scoring system for the self-rating tool. Specifically, the study sought answers to the following objectives: 1. Design the mathematical framework of scoring STEAM educators' proficiency; 2. Design the program for scoring STEAM educators' proficiency; 3. Validate the designed assessment/scoring program; and 4. Try-out and pilot test STEAM educator's proficiency scoring framework.

METHODS

The proficiency scoring framework crafted and elucidated in the following is a product in response to a fundamental question that we think the formalism should be able to answer: How do we extract and therefore determine ones proficiency from the self-rating survey data alone without any external assumption and thereby self-contained? The answer to this is exemplified in the next paragraphs, including an illustration determining the proficiency of a higher education STEAM teacher. A three tier validation, involving both quantitative and qualitative validations, were performed to the scoring framework and program. The results of pilot testing can be seen in the next section.

We wish to know the national STEAM educators' proficiency profile in a) the seven domains of the PPST, and b) the seven TPACK dimensions, from data gathered in the online administration of the developed self-rating survey (Morales et al. 2019) to n higher education STEAM teachers nationwide. The PPST's seven domains are in 1) content knowledge and pedagogy, 2) learning environment, 3) diversity of learners, 4) curriculum and planning, 5) assessment and reporting, 6) community linkages and professional engagement, and 7) personal growth and professional development. The seven TPACK dimensions are 1) pedagogical content knowledge (PCK), 2) technological pedagogical knowledge (TPK), 3) technological pedagogical content knowledge (TPCK), 4) technological content knowledge (TCK), 5) technological knowledge (TK), 6) pedagogical knowledge (PK), and 7) content knowledge (CK). We express the STEAM educators' proficiency as a) beginner, b) proficient, c) highly proficient, and d) distinguished in each of the seven domains and seven dimensions. We include as well the proficiency profile and proficiency in the overall domain.

National Proficiency Profile

Let R_{ijk}, the STEAM educator's proficiency profile of the j^{th} higher education STEAM teacher-respondent in the k^{th} PPST domain, be defined as

$$R_{ijk} = \frac{\text{total } i^{th} \text{ choice } j^{th} \text{ respondent chose in items in the } k^{th} \text{ domain}}{\text{total items in the } k^{th} \text{ domain}}, \tag{1}$$

where $i = 0, 1, 2, 3, 4,$ with $i = 0$ corresponding to choice "Not Applicable" (NA), $i = 1$ corresponding to choice "Rarely true to myself" (Rarely-ttm), $i = 2$ corresponding to choice "Occasionally true to myself" (Occasionally-ttm), $i = 3$ corresponding to "Often true to myself" (Often-ttm), and $i = 4$ corresponding to "Always true to myself" (Always-ttm), as choices on all items of the self-rating survey; $j = 1, 2, \dots, n;$ and $k = 1, 2, \dots, 7$. Similarly, we define the STEAM educator's proficiency profile of the j^{th} higher education STEAM teacher-respondent in the k^{th} TPACK dimension, T_{ijk} as

$$T_{ijk} = \frac{\text{total } i^{th} \text{ choice } j^{th} \text{ respondent chose in items in the } k^{th} \text{ dimension}}{\text{total items in the } k^{th} \text{ dimension}}. \tag{2}$$

R_{ijk} and T_{ijk} obey the normalization property

$$\sum_{i=0}^{4} R_{ijk} = \sum_{i=0}^{4} T_{ijk} = I_{jk} = 1, \tag{3}$$

because each teacher-respondent is required to respond on every item by choosing one and only one choice.

The national STEAM proficiency profile of the sample population corresponding to the i^{th} choice in the k^{th} domain and k^{th} dimension are measured with the following means given by

$$\overline{R}_{ik} = \frac{1}{n}\sum_{j=1}^{n} R_{ijk}\,, \qquad \overline{T}_{ik} = \frac{1}{n}\sum_{j=1}^{n} T_{ijk}. \tag{4}$$

Each domain contributes equally to the overall proficiency profile of the sample population. The domain-based overall proficiency profile then is

$$\overline{G}_i = \frac{1}{7}\sum_{k=1}^{7} \overline{R}_{ik}. \tag{5}$$

The national STEAM educators' proficiency profiles in eq. (4) and eq. (5) satisfy the normalization conditions

$$\sum_{i=0}^{4} \overline{R}_{ik} = \sum_{i=0}^{4} \overline{T}_{ik} = I_k = 1, \text{ and } \sum_{i=0}^{4} \overline{G}_i = 1, \quad (6)$$

which follows directly from eq. (3).

Knowing Ones Proficiency Profile and Proficiency

Any STEAM teacher wishing to check his/her level of proficiency may do so by taking the 60 item self-rating survey. Once completed, the teacher's proficiency profiles are calculated using

$$R_{ik} \equiv R_{i1k} = \sum_{j=1}^{n} \delta_{1j} R_{ijk}, \qquad T_{ik} \equiv T_{i1k} = \sum_{j=1}^{n} \delta_{1j} T_{ijk}. \quad (7)$$

where δ_{lj} is the Kronecker delta having the property $\delta_{lj} = \begin{cases} 0 & l \neq j \\ 1 & l = j \end{cases}$. A STEAM teacher's proficiency profile also satisfy the normalization conditions

$$\sum_{i=0}^{4} R_{ik} = \sum_{i=0}^{4} T_{ik} = I_k = 1. \quad (8)$$

A STEAM teacher's proficiency profile is then compared to the national STEAM educators' proficiency profile, calculated using eq. (4), by taking their difference like so $\Delta R_{ik} = R_{ik} - \overline{R}_{ik}$ and $\Delta T_{ik} = T_{ik} - \overline{T}_{ik}$. The proficiency profiles' normalization properties in eq. (3), (6), and (8) will ensure that, for any PPST domain or TPACK dimension, any one and only one of the five differences $\Delta R_{4k}, \Delta R_{3k}, \Delta R_{2k}, \Delta R_{1k},$ and ΔR_{0k} $(\Delta T_{4k}, \Delta T_{3k}, \Delta T_{2k}, \Delta T_{1k},$ and $\Delta T_{0k})$ will obtain the greatest positive difference, thereby determining uniquely the teacher's proficiency using the difference-proficiency association in Table 1. Print out or email generated by the program spells out the general attributes and the per domain attributes of the teacher's proficiency level.

Table 1. Translating difference in proficiency profile to teacher's proficiency.

Greatest Positive Difference	STEAM Teacher's Proficiency
$\Delta R_{4k}(\Delta T_{4k})$	Distinguished (i = 4) in domain (dimension) k
$\Delta R_{3k}(\Delta T_{3k})$	Highly Proficient (i = 3) in domain (dimension) k
$\Delta R_{2k}(\Delta T_{2k})$	Proficient (i = 2) in domain (dimension) k
$\Delta R_{1k}(\Delta T_{1k})$	Beginner (i = 1) in domain (dimension) k
$\Delta R_{0k}(\Delta T_{0k})$	Not Observed (i = 0) in domain (dimension) k

In the following illustration, the scoring framework is applied to $n = 1507$ higher education STEAM educators who had participated in the online self-rating survey at the time this investigation started which is roughly 78% of the total sample population of the study provided by 123 randomly selected universities and colleges from a total of 2,299 Philippine higher education institutions.

For instance, the self-rating survey data says that the national STEAM educators' proficiency profile of higher education institutions corresponding to PPST's domain on content knowledge and pedagogy, calculated using eq. (4) with $k = 1, n = 1507$, are as follows explicitly: Always-ttm $(i = 4)$, $\overline{R}_{41} = 0.37$; Often-ttm $(i = 3)$, $\overline{R}_{31} = 0.44$; Occasionally-ttm $(i = 2)$, $\overline{R}_{21} = 0.14$, Rarely-ttm $(i = 1)$, $\overline{R}_{11} = 0.03$, NA $(i = 0)$, $\overline{R}_{01} = 0.02$. Suppose now, a higher education STEAM teacher who has taken the 60-item self-rating survey have a proficiency profile in the PPST's content knowledge and pedagogy domain given explicitly by: Always-ttm $(i = 4), R_{41} = 4/19 \cong 0.21$, Often-ttm $(i = 3), R_{31} = 6/19 \cong 0.32$, Occasionally-ttm $(i = 2), R_{21} = 5/19 \cong 0.26$, Rarely-ttm $(i = 1), R_{11} = 3/19 \cong 0.16$, NA $(i = 0), R_{01} = 1/19 \cong 0.05$. Using Table 1, we say that the teacher is a beginner STEAM teacher in the PPST's content knowledge and pedagogy domain. The illustration just shown is extended to the other PPST domains, TPACK dimensions and overall PPST domain to complete the level of proficiency unique to the teacher.

Scoring Program and Validation

The derived mathematical eq. (4) and eq. (5) directed the development of the scoring programs using Microsoft excel and Fortran. Three tier validation (quantitative and qualitative) through participant responses determined the robustness and soundness of the scoring program. For the quantitative validation, the sampling ensured nationwide coverage. Respondents received the survey and replied to them online using google form. Once all prospective replies in google form are in, these are converted into Excel file for the convenient and automatic calculation of the a) ratios in eq. (1) and (2); and b) means in eq. (4) and (5). Likewise, the proficiency profiles in eq. (4) and (5) are calculated independently using Fortran. The Fortran codes are produced and saved as f95 file with respondents' replies converted into input txt file. These files are compiled to produce the proficiency profiles. Comparison and equivalence of the proficiency profiles established through the scoring programs using Microsoft Excel and Fortran determined the first-tier quantitative validation of the programs.

The second tier validation involves the calculation and comparison of the proficiencies of STEAM teachers, who 1) have taken the online, self-rating survey, and 2) were observed in classrooms. The proficiencies were determined through the Fortran implementation of the scoring framework using data from a) the self-rating survey, and b) the classroom observation ratings of observers. Validity is established once the program results show the presence of agreement on the proficiencies of teachers obtained a) according to oneself, and b) from an observer in the classroom.

The third tier emphasized a qualitative validation by comparing generated codes in the interview transcript and observation notes of the participant in each career stage emerging as incurring the same measure in the online survey and in the classroom rating scale (2nd tier) and the significant attributes underscored in all PPST domains and strands in each domain and TPACK dimensions. The proponents noted and assessed the equivalence of the indicators in the online survey as clustered in each domain for equivalence and presence in the interview transcript and observation notes to establish the validity.

RESULTS

The implementation of the analytic expressions of the proficiency profiles, including the determination of proficiencies of teachers, specified in the methods section are herein explained in detail. The results of validations and pilot tests are presented here as well.

Figure 1 shows the result (the value appearing in element T597) of the Excel implementation of eq. (1) corresponding to a teacher-respondent's ($j = 597 - 1$) "always true to myself" choice ($i = 4$) on the 19 items of Domain 1 ($k = 1$). The ratios appearing in columns U, V, W, and X, were for "often true to myself" ($i = 3$), "occasionally true to myself" ($i = 2$), "rarely true to myself" ($i = 1$), and "not applicable" ($i = 0$) choices, respectively. In each and every row, the elements in columns T, U, V, W, and X, sums up to unity, consistent with the normalization property, eq. (3), of the proficiency profile. The same Excel implementation of eq. (1) was done to the other 6 domains. The same Excel implementation was employed to the 7 dimensions using eq. (2).

Figure 2 shows the results of the Excel implementation of eq. (5). Elements BI1533, BJ1533, BK1533, BL1533, and BM1533, corresponding to $\overline{G}_4, \overline{G}_3, \overline{G}_2, \overline{G}_1$, and $\overline{G}_0$ in eq. (5), respectively, are collectively called the overall national STEAM proficiency profile in the PPST domain. Element BN1533 confirms the normalization property of the $\overline{G}_i$'s in eq. (6). The numbers appearing in elements BI1512, BJ1512, BK1512, BL1512, BM1512 are results of Excel implementation of $\overline{R}_{41}$, $\overline{R}_{31}$, $\overline{R}_{21}$, $\overline{R}_{11}$, and $\overline{R}_{01}$ in eq. (4), respectively. These elements collectively correspond to the national STEAM proficiency profile in the PPST's content knowledge and pedagogy domain. Elements BN1512, BN1515, BN1518, BN1521, BN1524, BN1527, and BN1530 verify that the $\overline{R}_{ik}$'s satisfy the normalization property eq. (6).

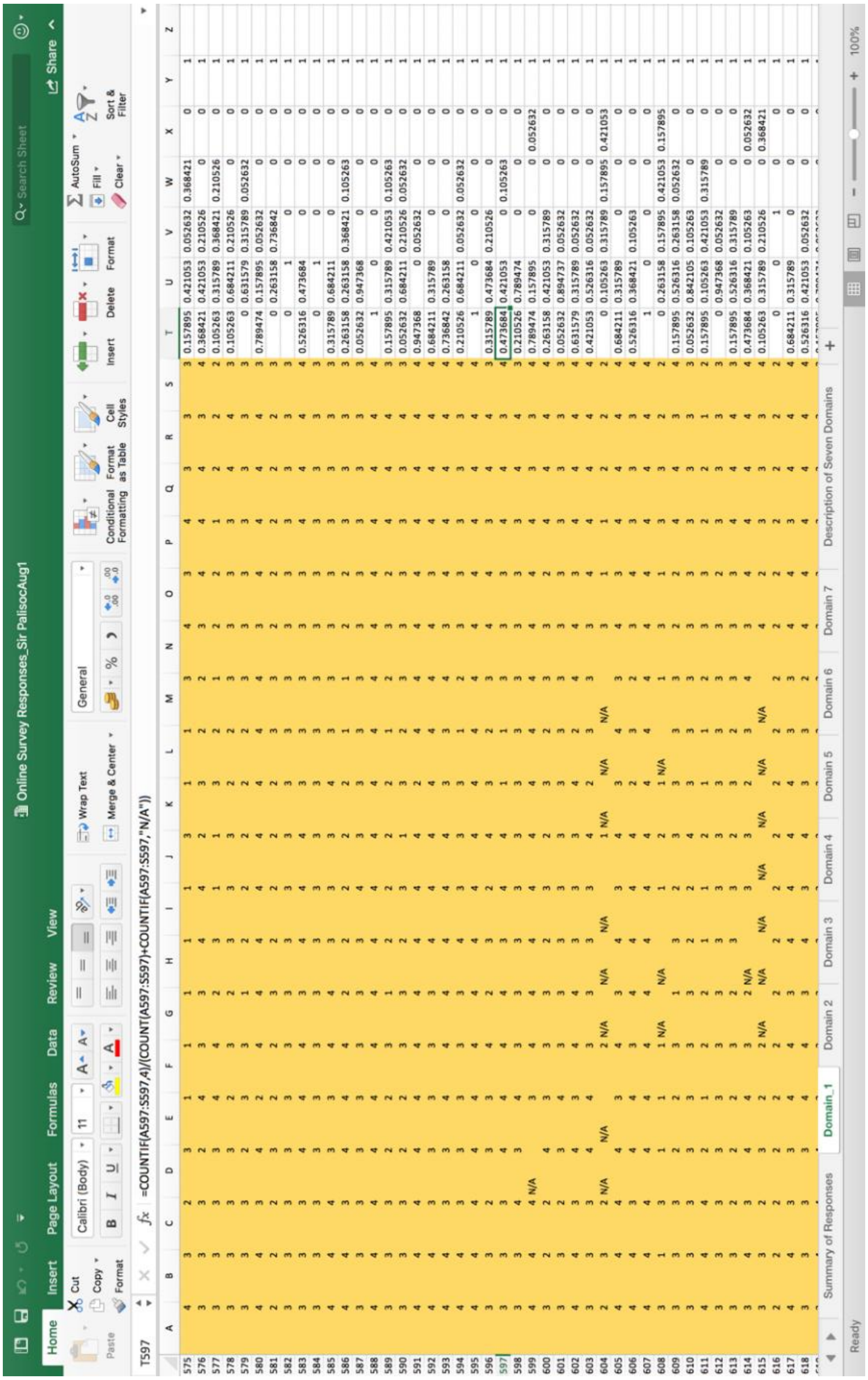

Figure 1. Excel implementation of equation 1.

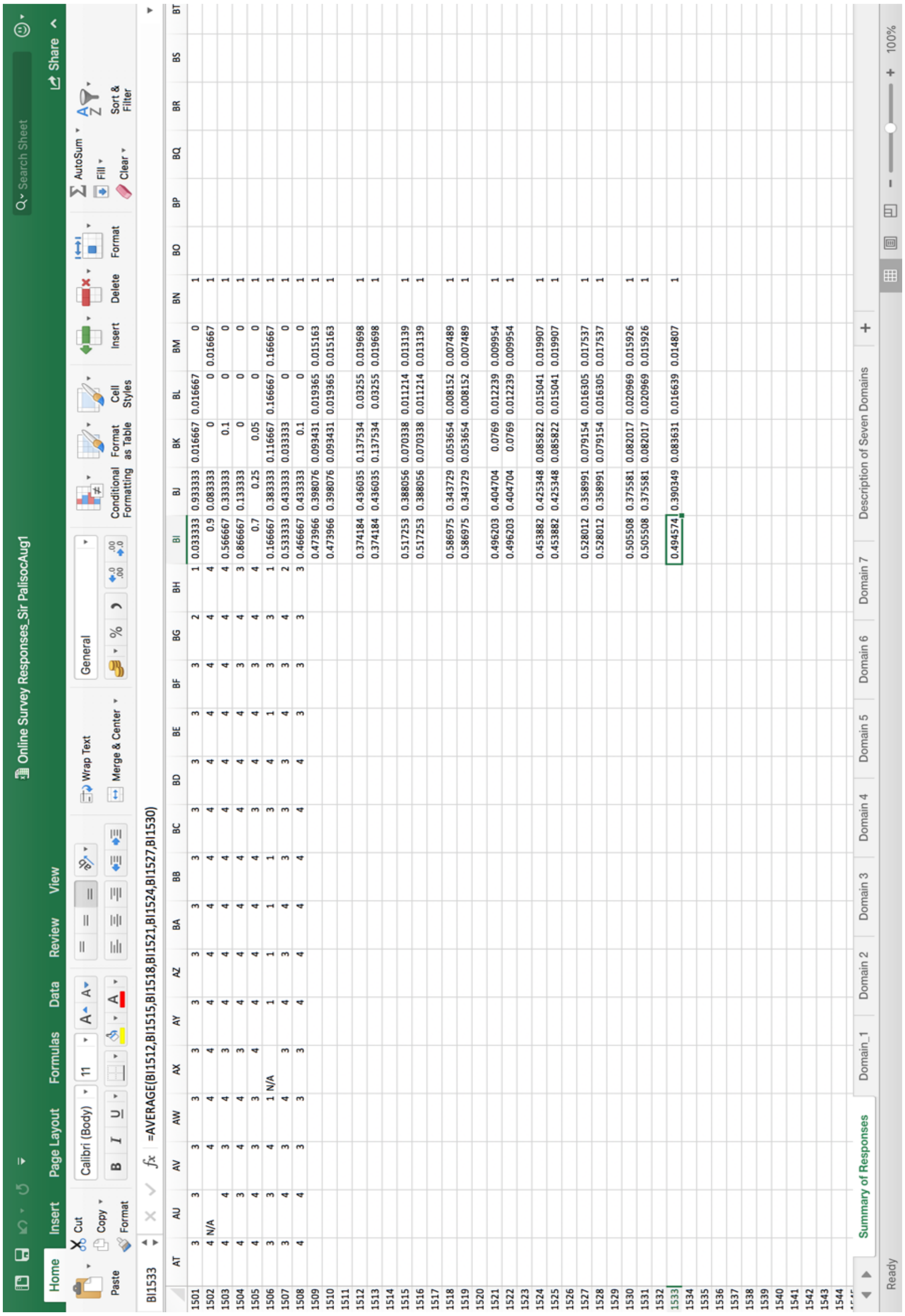

Figure 2. Excel implementation of equation 5.

Figure 3 shows the initial part of the Fortran program code named proficiency that implemented eq. (1), eq. (4) and eq. (5). It starts by uploading (using the Fortran command open(10,file='Domain1.txt')) the responses of the 1,507 teacher-respondents to the 19 items covering domain one stored in a data file named Domain1.tex. Henceforth, until after the 4th "end do" Fortran statement, eq. (1) is implemented, for each response of every teacher-respondent in domain 1, and stored in codes R4(j), R3(j), R2(j), R1(j), and R0(j).

```
program proficiency
integer, dimension(2000,20)  :: f,ff
real, dimension(10,13) :: NAF1
real, dimension(2000) :: R4
real, dimension(2000) :: R3
real, dimension(2000) :: R2
real, dimension(2000) :: R1
real, dimension(2000) :: R0
integer               :: i
integer               :: j
real :: answer,x,y,x1,y1,z1
real :: DIF10,HDF10,PRF10,BIF10,NAF10
real :: DIF11,HDF11,PRF11,BIF11,NAF11
real :: NORMAL,NORMAL1,NORMAL2
real :: RR4,AVR4,AVR41,AVR42
real :: RR3,AVR3,AVR31,AVR32
real :: RR2,AVR2,AVR21,AVR22
real :: RR1,AVR1,AVR11,AVR12
real :: RR0,AVR0,AVR01,AVR02
real :: NORMAL3,NORMAL4,NORMAL5
real :: AVR43,AVR44,AVR45
real :: AVR33,AVR34,AVR35
real :: AVR23,AVR24,AVR25
real :: AVR13,AVR14,AVR15
real :: AVR03,AVR04,AVR05
real :: NORMAL6,NORMAL7
real :: AVR46,AVR47
real :: AVR36,AVR37
real :: AVR26,AVR27
real :: AVR16,AVR17
real :: AVR06,AVR07
open(10,file='Domain1.txt')
do j=1,1507
do i=1,1
read(10,*) f(j,i),f(j,i+1),f(j,i+2),f(j,i+3),f(j,i+4),f(j,i+5),f(j,i+6),f(j,i+7),f(j,i+8),f(j,i+9),f(j,i+10),f(j,i+11) &
   ,f(j,i+12),f(j,i+13),f(j,i+14),f(j,i+15),f(j,i+16),f(j,i+17),f(j,i+18)
end do
end do
do j=1,1507
DIF11=0
HPF11=0
PRF11=0
BIF11=0
NAF11=0
DIF10=0
HPF10=0
PRF10=0
BIF10=0
NAF10=0
do i=1,19
        if (f(j,i)==4) then
        DIF11=DIF10+1.0
        else if (f(j,i)==3) then
        HPF11=HPF10+1.0
        else if (f(j,i)==2) then
        PRF11=PRF10+1.0
        else if (f(j,i)==1) then
        BIF11=BIF10+1.0
        else if (f(j,i)==5) then
        NAF11=NAF10+1.0
        else
        print *, f(j,i)
OverallDomain.f95
```

Figure 3. Fortran implementation of equation 1.

Then, from the last "do – end do" loop statement until the start of the implementation of domain 2, eq. (4) is implemented for domain 1, stored in codes AVR41, AVR31, AVR21, AVR11, AVR01, and printed, as shown in Figure 4.

```
        HPF10=0
        PRF10=0
        BIF10=0
        NAF10=0
        do i=1,19
                if (f(j,i)==4) then
                DIF11=DIF10+1.0
                else if (f(j,i)==3) then
                HPF11=HPF10+1.0
                else if (f(j,i)==2) then
                PRF11=PRF10+1.0
                else if (f(j,i)==1) then
                BIF11=BIF10+1.0
                else if (f(j,i)==5) then
                NAF11=NAF10+1.0
                else
                print *, f(j,i)
                end if
                DIF10=DIF11
                HPF10=HPF11
                PRF10=PRF11
                BIF10=BIF11
                NAF10=NAF11
        R4(j)=DIF11/i
        R3(j)=HPF11/i
        R2(j)=PRF11/i
        R1(j)=BIF11/i
        R0(j)=NAF11/i
        NORMAL=R4(j)+R3(j)+R2(j)+R1(j)+R0(j)
        end do
        end do
        RR4=0
        RR3=0
        RR2=0
        RR1=0
        RR0=0
        do j=1,1507
           RR4=RR4+R4(j)
           RR3=RR3+R3(j)
           RR2=RR2+R2(j)
           RR1=RR1+R1(j)
           RR0=RR0+R0(j)
        end do
        AVR4=RR4/(j-1)
        AVR3=RR3/(j-1)
        AVR2=RR2/(j-1)
        AVR1=RR1/(j-1)
        AVR0=RR0/(j-1)
        NORMAL=AVR4+AVR3+AVR2+AVR1+AVR0
        AVR41=AVR4
        AVR31=AVR3
        AVR21=AVR2
        AVR11=AVR1
        AVR01=AVR0
        NORMAL1=NORMAL
        print *, AVR41, j-1
        print *, AVR31, j-1
        print *, AVR21, j-1
        print *, AVR11, j-1
        print *, AVR01, j-1
        print *, NORMAL1
        !Start of Domain 2
:
```

Figure 4. Continuation of Figure 3 including the Fortran implementation of eq. (4)

The procedure just described is repeated for the remaining 6 domains in preparation for the implementation of eq. (5) shown in Figure 5. The Fortran code program proficiency is then compiled to run the program and extract the results into a default file a.out, the result of which is shown in Figure 6 and the basis of Table 2.

The first tier validation says that the national STEAM proficiency profile for both PPST domains and TPACK dimensions determined through Microsoft excel agree with Fortran results with 1,507 as the total number of sample respondents.

```
            DIF10=DIF11
            HPF10=HPF11
            PRF10=PRF11
            BIF10=BIF11
            NAF10=NAF11
      R4(j)=DIF11/i
      R3(j)=HPF11/i
      R2(j)=PRF11/i
      R1(j)=BIF11/i
      R0(j)=NAF11/i
      NORMAL=R4(j)+R3(j)+R2(j)+R1(j)+R0(j)
      end do
      end do
      RR4=0
      RR3=0
      RR2=0
      RR1=0
      RR0=0
      do j=1,1507
         RR4=RR4+R4(j)
         RR3=RR3+R3(j)
         RR2=RR2+R2(j)
         RR1=RR1+R1(j)
         RR0=RR0+R0(j)
      end do
      AVR4=RR4/(j-1)
      AVR3=RR3/(j-1)
      AVR2=RR2/(j-1)
      AVR1=RR1/(j-1)
      AVR0=RR0/(j-1)
      NORMAL=AVR4+AVR3+AVR2+AVR1+AVR0
      AVR47=AVR4
      AVR37=AVR3
      AVR27=AVR2
      AVR17=AVR1
      AVR07=AVR0
      NORMAL7=NORMAL
      print *, AVR47, j-1
      print *, AVR37, j-1
      print *, AVR27, j-1
      print *, AVR17, j-1
      print *, AVR07, j-1
      print *, NORMAL7
      AVR4=0
      AVR3=0
      AVR2=0
      AVR1=0
      AVR0=0
      NORMAL=0
      AVR4=(AVR41+AVR42+AVR43+AVR44+AVR45+AVR46+AVR47)/7
      AVR3=(AVR31+AVR32+AVR33+AVR34+AVR35+AVR36+AVR37)/7
      AVR2=(AVR21+AVR22+AVR23+AVR24+AVR25+AVR26+AVR27)/7
      AVR1=(AVR11+AVR12+AVR13+AVR14+AVR15+AVR16+AVR17)/7
      AVR0=(AVR01+AVR02+AVR03+AVR04+AVR05+AVR06+AVR07)/7
      NORMAL=AVR4+AVR3+AVR2+AVR1
      print *, AVR4
      print *, AVR3
      print *, AVR2
      print *, AVR1
      print *, AVR0
      print *, NORMAL
      end  program proficiency
(END)
```

Figure 5. Fortran implementation of equation 5.

```
~/Proficiency — -bash                                    ~/Proficiency — -bash
Last login: Fri Dec  7 08:32:08 on ttys001
TPACK-STEAMs-MacBook-Pro-3:~ tpack-steam$ cd Proficiency/
TPACK-STEAMs-MacBook-Pro-3:Proficiency tpack-steam$ gfortran OverallDomain.f95
TPACK-STEAMs-MacBook-Pro-3:Proficiency tpack-steam$ ./a.out
  0.374184340          1507
  0.436035812          1507
  0.137534022          1507
   3.25497948E-02      1507
   1.96975358E-02      1507
   1.00000143
  0.517253101          1507
  0.388055980          1507
   7.03382790E-02      1507
   1.12143420E-02      1507
   1.31386947E-02      1507
   1.00000036
  0.586974680          1507
  0.343728870          1507
   5.36544099E-02      1507
   8.15243460E-03      1507
   7.48886215E-03      1507
  0.999999225
  0.496202856          1507
  0.404704273          1507
   7.69005343E-02      1507
   1.22391675E-02      1507
   9.95354448E-03      1507
   1.00000036
  0.453882277          1507
  0.425348103          1507
   8.58217999E-02      1507
   1.50409220E-02      1507
   1.99071132E-02      1507
   1.00000024
  0.528012097          1507
  0.358990401          1507
   7.91545659E-02      1507
   1.63048655E-02      1507
   1.75372064E-02      1507
  0.999999046
  0.505507231          1507
  0.375581056          1507
   8.20171237E-02      1507
   2.09688265E-02      1507
   1.59256775E-02      1507
  0.999999940
  0.494573802
  0.390349209
   8.36315304E-02
   1.66386198E-02
   1.48069477E-02
   1.00000012
TPACK-STEAMs-MacBook-Pro-3:Proficiency tpack-steam$
```

Figure 6. Compilation of Fortran code with gfortran and viewing of results with ./.

Table 2 shows the national STEAM proficiency profile based on the PPST domains. On the average, it appears that, overall nationally, for a "rarely true to oneself" choice chosen on an item, five other items received "occasionally true to oneself" response, while "often true to oneself" choice were chosen in 24 other items, and 30 other items got "always true to oneself" choice.

Table 2. National STEAM educator's proficiency profile in the Philippine Professional Standards for Teachers (PPST) domains. ** true to myself are herein implied for simplicity from here onwards.

PPST Domain	Always**	Often**	Occasionally**	Rarely**	NA
Content Knowledge and Pedagogy	0.37	0.44	0.14	0.03	0.02
Learning Environment	0.52	0.39	0.07	0.01	0.01
Diversity of Learners	0.59	0.34	0.05	0.01	0.01
Curriculum and Planning	0.50	0.40	0.08	0.01	0.01
Assessment and Reporting	0.45	0.42	0.09	0.02	0.02
Community Linkages and Professional Engagement	0.53	0.36	0.08	0.02	0.01
Personal Growth and Professional Development	0.50	0.38	0.08	0.02	0.02
Overall	0.49	0.39	0.08	0.02	0.02

Table 3 shows the national STEAM educator's proficiency profile based on the 7 TPACK dimensions. On the average, out of the 13 items of the self-rating survey dealing directly on the pedagogical knowledge dimension, around seven items received "always true to myself" response, roughly five other items got "often true to myself" answer, and close to an item obtain an "occasionally true to myself" reply. Choices "rarely true to myself" and "not applicable" were hardly chosen in this dimension.

For the second-tier validation, the online, self-rating survey's sample population used was 1,455 teacher-respondents, the proficiency profiles of which (see Table 4) in domains 1) content knowledge and pedagogy, 2) learning environment, and 3) diversity of learners, formed the basis for determining the proficiency level of 52 other teachers who took the online survey and were observed in classroom as well.

Table 3. National STEAM educator's proficiency profile in the Technological-Pedagogical-Content-Knowledge (TPACK) dimensions.

TPACK Dimension	Always	Often	Occasionally	Rarely	NA
Pedagogical Content Knowledge	0.54	0.36	0.07	0.01	0.02
Technological Pedagogical Knowledge	0.50	0.41	0.07	0.01	0.01
Technological Pedagogical Content Knowledge	0.30	0.44	0.18	0.05	0.03
Technological Content Knowledge	0.43	0.43	0.10	0.02	0.02
Technological Knowledge	0.48	0.38	0.09	0.02	0.03
Pedagogical Knowledge	0.56	0.37	0.06	0.01	0.00
Content Knowledge	0.45	0.44	0.09	0.01	0.01

Table 4. STEAM proficiency profile of 1455 online survey teacher-respondents.

Domain	Always	Often	Occasionally	Rarely	NA
Content Knowledge and Pedagogy	0.38	0.43	0.14	0.03	0.02
Learning Environment	0.52	0.39	0.07	0.01	0.01
Diversity of Learners	0.59	0.34	0.05	0.01	0.01

Finally, Table 5 presents the third tier of validation focused on identifying presence or occurrence of indicators in the interview transcripts and classroom observation notes matched with the expected attribute per career stage as per PPST.

Table 6 shows the STEAM proficiency profiles of a teacher classified as distinguished overall (Teacher A), including in all domains except in Domain 5, where the teacher appears to be highly proficient only; a teacher envisaged as highly proficient overall, including in all domains except in Domain 7, where the teacher appears to be distinguished (Teacher B); and a teacher proficient in Domain 3 and beginner in Domain 1 (Teacher C).

Table 5. Qualitative validation of the scoring program. The shaded portion indicate non-match of interview transcript or classroom observation notes with the expected attribute per career stage as per Philippine Professional Standards for Teachers (PPST). Data element having two values mean data comes from two respondents.

Domain	Distinguished		Highly Proficient		Proficient		Beginner	
	I	CON	I	CON	I	CON	I	CON
Content Knowledge and Pedagogy • composed of 7 strands • with 19 items (Online Survey)	18	3		14 6	11	10	10	10
Learning Environment • composed of 6 strands • with 10 items (Online Survey)	3		6 4	3 2	5	4	6	6
Diversity of Learners • composed of 5 strands • with 7 items (Online Survey)	3	1	5 2	2 1	1	5	6	3
Curriculum and Planning • composed of 5 strands • with 9 items (Online Survey)	3	3	3 4	4 3	5 4	5 5	0	4
Assessment and Reporting • composed of 5 strands • with 3 items (Online Survey)	1	1	3 3	0 1	3 1	1 1	1	1
Community Linkages and Professional Engagement • composed of 4 strands • with 7 items (Online Survey)	5	1	5	0	3	0	4	2
Professional Growth and Professional Development • composed of 5 strands • with 5 items (Online Survey)	3		2	1	1	1	3	1

I-Interview, CON – classroom observation notes

Table 6. STEAM proficiency profiles of higher education teachers A (TA), B (TB), and C (TC), determined, respectively, as distinguished overall, highly proficient overall, and proficient in domain 3 and beginner in domain 1 in the PPST domain.

Domain	Always			Often			Occasionally			Rarely			NA		
	TA	TB	TC	TA	TB	TC	TA	TB	TC	TA	TB	TC	TA	TB	TC
Content Knowledge and Pedagogy	0.47	0.31	0.21	0.42	0.53	0.42	0.00	0.16	0.10	0.11	0.00	0.16	0.00	0.00	0.11
Learning Environment	1.00	0.00	0.50	0.0	0.90	0.50	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diversity of Learners	0.86	0.43	0.57	0.14	0.57	0.29	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00
Curriculum and Planning	0.56	0.44	0.56	0.33	0.56	0.11	0.11	0.00	0.22	0.00	0.00	0.11	0.00	0.00	0.00
Assessment and Reporting	0.00	0.00	0.67	0.67	1.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
Community Linkages and Professional Engagement	0.86	0.43	0.86	0.14	0.43	0.00	0.00	0.14	0.00	0.00	0.00	0.14	0.00	0.00	0.00
Personal Growth and Professional Development	0.80	0.80	0.80	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00
Overall	0.65	0.34	0.59	0.27	0.60	0.24	0.02	0.06	0.07	0.01	0.00	0.09	0.05	0.00	0.01

DISCUSSION

A self-contained mathematical framework, free from external assumptions, able to unambiguously determine a higher education STEAM teacher's proficiency is formulated in this study. On the basis of this framework, a program is designed and subjected to quantitative and qualitative validation showing meaningful and consistent prediction of STEAM teachers' proficiency. A pilot test of this program to three STEAM teachers of varying levels of proficiency indeed shows its capacity to identify uniquely a STEAM teacher's proficiency. These results are necessary to make sense of the developed self-rating tool in Morales et al. (2019) in providing STEAM teachers with their equivalent rating in terms of STEAM Education proficiency. Consequently, the STEAM educator's proficiency scoring framework ably determines the proficiency profile of a target population and predict unambiguously individual teacher-respondent's proficiency level. The outputs of the previous work and the current study form part of a bigger project on developing the Philippine STEAM Education Model for higher and advanced learning. The novelty of this study (a) is that it provided the self-rating tool in Morales et al. (2019) a programmed framework of scoring which other and most developed instruments lack, and (b) lies in the quantitative and qualitative combination of approaches to validation of the STEAM educators' scoring framework, which, to the best of our knowledge, is unique to this study.

The developed framework, including the program it took form, in determining a Philippine higher education STEAM teacher's proficiency is self-contained, universal, albeit shaped by local peculiarities, transparent, and technology-enhanced (Steel 2015). The determination of ones' proficiency depends entirely and sufficiently on the population of the self-rating survey through the national STEAM educators' proficiency profiles as shown in Tables 2 and 3. External assumption is not necessary. The scoring framework's adaptability is universal provided the survey used require one and only one response on every item, which may be adapted to suit any local setting—a trait matching the characteristics of the seven principles of universal design (Center for Excellence in Universal Design 2019). The formulated framework and program give results that any interested investigator may verify independently given the same set of data.

The framework's and program's unique determination of ones' proficiency have been quantitatively and qualitatively validated with varying presence of agreement. The presence of agreement in the proficiency level of teachers according to oneself and from an observer in the classroom is shown in Table 7. Out of the 52 teachers who took the online survey and were likewise observed in class, three teachers were determined as proficient in domain on diversity of learners in both online survey and classroom observation, which translates to 50% agreement, considering there were six teachers predicted as proficient in the domain on diversity of learners through the online survey. Except in the domains on learning environment and on diversity of learners, both of which practically have no beginners, distinguished teachers in the domain on learning environment exhibits the least amount of agreement with 7%.

Table 7. Extent of agreement on proficiency level of teachers according to oneself and from an observer in the classroom.

Domain	Distinguished	Highly Proficient	Proficient	Beginner
Content Knowledge and Pedagogy	1 [11] 9%	3 [20] 15%	5 [15] 33%	2 [6] 33%
Learning Environment	1 [14] 7%	8 [32] 25%	1 [5] 20%	0 [1] 0%
Diversity of Learners	6 [19] 32%	7 [26] 27%	3 [6] 50%	0 [1] 0%

The occurrence of indicators may mean that outputs generated by the scoring program match the indicators as perceived by classroom observers and interviewers of the participants identified for validation test (Table 5). The decreasing trend may imply that in most of the domains, 4 of 7, proficiency in STEAM teaching may be dictated by the number of indicators exhibited by the STEAM educator(s) in the following domains: domain 1-content knowledge and pedagogy, domain 5-assessment and reporting, domain 6-community linkages and professional engagement, and domain 7-professional growth and development, with the greatest number of combination for the distinguished career stage and the least for the beginner stage. For example, distinguished teacher in domain 1 as rated by the scoring program based on the online self-rating survey exhibited 18 out of 19 indicators as per interview transcripts and 3 out of 19 as per classroom observation notes with a decreasing combination until the beginner stage. However, three of the seven domains did not exhibit the same trend, noting greater number of indicators exhibited by other career stages compared to the distinguished career stage. Analysis of the sample interview transcripts and classroom observation notes in Table 8 shows that although the three domains (Learning Environment, Diversity of Learners, and Curriculum and Planning) manifested a different trend in terms of number of exhibited indicators, the minimally exhibited indicator encompass large number of indicators with complex attribute.

Table 8. Sample interview transcripts and classroom observation notes per career stage.

Domain	Indicator	Distinguished	Highly Proficient	Proficient	Beginner
2: Learning Environment	13. Models various scientific attitude and STEAM professional traits	Researches for problem solving Conducts research to help industry in the province and to ease environmental difficulty	Read books; critical thinking; preparedness	Dedication to work	facilitated students' smooth/emotional disposition during the presentation upgrade self regularly
4: Curriculum and Planning	43. Designs, communicates, and implements STEAM-related activities in partnership with the community/industry.	Produces products like lutana tea, aspherkol and other innovative products	Ask students to develop a project to identify a burglar from not a burglar using machine vision (using GPS)	Actively participates in professional activities	Conduct capstone project and look for possible problems in the industry

The distinguished teacher's conduct of STEAM research and utilization of such research in STEAM teaching traverse wide array of domains that includes all the three aforementioned domains (Hazelkorn et al. 2015). Comparing this exhibited attribute, teachers in other career stages specified minute attributes compared to those exhibited by the distinguished teacher, indicative of validation of the scoring system developed for the online survey to generate the STEAM educator proficiency.

The scope of the scoring framework developed is universal and may be adapted to suit any local setting. Although all necessary aspects of validation were done and exhibited favorable results, increasing the number of interviews and classroom observations to 10% of the sample population of teachers will produce a robust scoring program.

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