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Experiences and Practices of STEM Teachers through the Lens of TPACK

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ABSTRACT

The study used the TPACK (Technological Pedagogical Content Knowledge) framework to determine the STEM (Science Technology Engineering Mathematics) teachers' experiences and practices. Data were sourced through interviews, classroom observations and document analysis from purposively selected 106 STEM teachers (from randomly identified universities/colleges of the 17 regions of the country). Three frameworks: Policies Standards and Guidelines (PSGs), Philippine Professional Standards for Teachers (PPST) and TPACK guided the analysis of the qualitative data. Exploratory design developed the visualization for the three education domains (pedagogy, assessment and technology integration) that represent teachers' experiences and practices. Findings revealed that teachers characterized the unique attributes of the domains defining the individual visualizations of these education domains. Re-thematization provided an image for the Philippine Higher Education Responsive Model (PHERM) which showed that STEM teachers develop one knowledge construct of TPACK at a time, the last being integrating technology. The developed model of STEM teachers' experiences and practices is envisioned to track and enhance the competencies of teachers to deliver 21st century-skilled STEM workforce for the Philippines.

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Introduction

Quality education is sought by every nation to address or mitigate critical problems such as poverty, hunger, and peace. Such broad reach brought several frameworks, models and agenda to ensure its attainment and even its sustainability. In fact, at the onset of industrial development (the fourth industrial revolution) which may seem to have brought some form of complexity and uncertainty to people (Rahman et al., 2017), education leaped to a new paradigm (Education 4.0) to attune learners to the new industrial environment. This shift targets learner preparation for jobs in the future with the necessary skill set. Even with the COVID-19 pandemic that instilled volatility, and ambiguity in all aspects, including education (UNESCO, 2020), learning continuity plans and frameworks surfaced to ensure low learning loss during the disruption. Hence, nations turn to education as the source of hope. Global organizations re-establish their education agenda, models and frameworks to help nations and countries achieve economic growth and development.

Quality in education focuses on processes, outcomes and trends. Agenda 2030, specifically sustainable development goal (SDG) 4, defines quality education as a means to produce the intended knowledge worker with relevant skills, and quality teachers (UN, 2015). While the intentions of the Agenda are profound, how such agenda and goals would be translated into workable plans and actions in the education system may matter the most. It may even be considered as the crucial point that distinguishes countries that are successful implementers of these models from those who lag behind. Within these premises, we sought to determine how our country (the Philippines) as a developing nation translates these models and agenda into concrete steps towards quality education. We documented and modelled the experiences of teachers to explore their pedagogical, assessment and technology integration practices. We modelled their practices to draw a holistic picture of what these teachers do and what they envision the education system to be in order to attain quality education. For our investigation, we focused on STEM, which is believed to dominate the skill-driven, highly influential and technologically-influenced industrial development we are experiencing. We foresee that our work will provide higher education institutions with guidance and constructs that will enable them to draw out evidence-based strategies and plans for better and quality STEM education.

Background of the Study

Much like the others, the country's effort to attune to Agenda 2030 includes staging the Philippine Development Plan 2017-2022 (NEDA, 2017) to target an accelerated human development program through quality higher education, and technical and vocational education. In response, the Philippine Quality Framework (PQF) mandates the Commission on Higher Education (CHED) to provide the country’s tertiary education with policies, standards and guidelines (PSGs) emanating the concept of outcomes-based education and quality assurance in the core competencies expected of every Filipino graduate. These PSGs (disseminated through CHED memoranda) mandate local universities to recalibrate their curricular programs along with specific contexts and institutional missions to assure quality education and to ensure quality graduates.

Apparently, the absence of a document or a blueprint for Philippine higher education institutions (HEIs) may have provided difficulty in translating the policies into concrete steps to curricular revisions attuned to the mandates. Such has prevented stakeholders from having a unified action to address issues in education including the aforementioned concerns. Hence, in pursuing quality education in general, and particularly in STEM programs, this study saw the need for an evidence-based and grounded blueprint (sourced from the experiences and practices of who we call experts from the ground—STEM teachers) for Philippine colleges and universities to attain quality higher education and sustain the human capital of the country. Integrated STEM is crucial to national economy and security. Ring et al. (2017) argued that global competitiveness is contingent on STEM. This is supported by Anito and Morales (2019) saying that the low global competitiveness metrics of the Philippines was due to the insufficient number of STEM professionals in the country. Studies and national data agree that national economic progress depends on the STEM workforce (English, 2016; Marginson et al., 2013) and that STEM literacy is crucial in ensuring economic growth (Mildenhall et al., 2019). Studies further show that the next generation jobs, including those that are still unknown, require high proficiency in STEM and STEM-related skills (Roehrig et al., 2012; Sharma & Yarlagadda, 2018). This is the reason why STEM education has received considerable attention among governments in the past decades (Banks & Barlex, 2014; Barlex, 2011) as evidenced by the huge budget percentage allocated to STEM education programs. Survey of literature across the globe shows that STEM education programs generally focus on three aspects; attracting and retaining more students to STEM programs (Alper, 1993; Halim & Subahan Mohd Meerah, 2016; Jones et al., 2018; Ring et al., 2017), enhancing the STEM curriculum and instruction for better STEM learning outcomes (Cantrell & Ewing-Taylor, 2009; Lamb et al., 2015; Lamb et al., 2018; Ring et al., 2017; Sharma & Yarlagadda, 2018; Thi To Khuyen et al., 2020), and strengthening teacher capacity in STEM (Sharma & Yarlagadda, 2018; Stohlmann et al., 2012). STEM programs aimed at increasing enrollment and retention of STEM students to the programs to address the so-called "leaking pipeline" (Alper, 1993; Berryman, 1983) wherein students lose their interest in the STEM program they are admitted to, and consequently fail to finish a STEM degree. Initiatives to advance STEM curriculum and instruction likewise emerged primarily to promote competencies in the STEM domain across all grade levels starting from grade school (Cantrell & Ewing-Taylor, 2009; Lamb et al., 2018; Ring et al., 2017). In terms of teacher capacity on STEM, research suggests that teachers' lack of sufficient STEM content and pedagogical knowledge results in poor student performance in STEM (Sharma & Yarlagadda, 2018; Stohlmann et al., 2012).

Why STEM?

Aiming for a sustainable knowledge capital dominated by STEM-skilled human resources is the goal of every country for knowledge economy and prosperity. Rothwell (2013) believed in ensuring a viable stream of STEM intellectual assets in two STEM economies: a) the professional STEM economy linked to graduate school education, and b) general STEM economy drawing from high schools, vocational schools, community colleges and universities. Both streams see the crucial role of education, particularly the school or university system (Sellami et al. 2017), in bringing quality education and training prospective recruits. Hence, the current study anchors on STEM in two lenses: 1) STEM as a cluster of courses that build skills for future jobs (Ahmed, 2016); and 2) STEM as an integrative approach to curriculum and education moored on curriculum integration theories (Corlu et al., 2014) to develop STEM literacy (Bybee, 2010). Both are capable of producing critical thinkers, innovators and problem solvers.

Influenced by the need for STEM- and STEM-related skilled workforce, STEM models and their implementation abound in literature (Dotson et al., 2020; Kelley et al., 2021; Kelley & Knowles, 2016; Simpson-Singleton & Che, 2019; Stracke et al., 2019;). Kelly and colleagues (2021) presented three STEM-models (STEM content inclusion, STEM content integration, STEM content and practices integration) and their differences in the implementation that focused on the teaching of STEM. The U.S. STEM Education Model that primarily aimed to increase enrolment in STEM degrees (Simpson-Singleton & Che, 2019) presented two sub-models: a) SimEd Absenteeism Model focused on teacher and student interactions, and b) SimEd "No Child Left Behind" that accommodated all other STEM education stakeholders. The Learn STEM Model developed by Stracke et al. (2019) emphasizes on the learners who shall become the owners of their own learning processes. All aforementioned models were created and implemented in developed and first world countries using simulations and mathematical modelling systems. However, the current study which was completed in a developing country with a more inferior technological capability depended so much on the qualitative data drawn from conversations with STEM teachers from the rural areas to deduce their practices and experience from where the Philippine STEM model was grounded.

STEM education can be considered as a complete paradigm to develop knowledge-intensive workers. Hence, this study posits that an evidence-based and grounded blueprint in concretizing country policies for STEM programs to attain quality higher education for the country may be derived from the teachers' experiences and ideals. These practices, experiences and ideals are interspersed with the integrative concepts drawn from STEM education, policies, standards and guidelines (PSGs) of STEM programs, Philippine professional standards for teachers (PPST) and the principles of tertiary teaching to draw out concrete visual constructs. Looking at these experiences, and ideals, and extracted ideas and concepts from the lens of TPACK may define a contextualized visualization of the Philippine STEM education that may guide the aforementioned constructs of higher education. TPACK describes the acquisition and demonstration of instructional experiences integrating content, pedagogy and technology in establishing effective instructional practice and environment (Koehler & Mishra, 2008). In context, the study looked into and exhausted all data sources (teachers, school leaders and documents) for the clustered program of CHED that included all disciplines in the sciences, technology, engineering, agriculture/fisheries and mathematics. While this investigation focuses on STEM as a paradigm, the study refers to the term 'teachers' as equivalent to teachers in higher education/university teachers (Bjerkholt et al., 2020).

Why TPACK in STEM?

Integrated STEM remains an elusive concept in STEM education (Brown et al., 2011; Bybee, 2013; English, 2016; Herschbach, 2014; Johnson, 2012). In fact, STEM education itself is loosely defined due to various interpretations, conceptions, and practices. There appears to be no general agreement among scholars on the definition (Herschbach, 2014; Stoeger et al., 2016; Wallace et al., 2015), classroom practices and curricular approach (Bullock, 2017; English, 2016; Ring et al., 2017), and even on quality indicators of successful STEM programs (Eisenhart et al., 2015). In terms of scope, some include ICT and ICT-related disciplines (Stoeger et al., 2016), others add health (Wallace et al., 2015), social sciences (Schultz et al., 2011), and Agriculture-Fisheries (Anito & Morales, 2019; Morales et al., 2019). Most importantly, the current concepts and practices of integrated STEM ranges from merely treating STEM as a replacement to any one of the four fields, especially the science and mathematics (Breiner et al., 2012; Bybee, 2013; Sanders, 2009), to fragmented integration of any two or three fields or full integration of the four fields (Fogarty, 1991). This is where STEM education finds its place as it is supposed to help strengthen the disciplinary (multidisciplinary, interdisciplinary, and transdisciplinary) integration of STEM (Peterman et al., 2017).

Promoting STEM integration through STEM education entails strong pedagogical and content knowledge among teachers, facilitated by their technological knowledge. As Scherer (2014) and Bybee (2010) claimed, STEM education requires a solid interplay between technology, pedagogy, and content. STEM education must ensure that teachers possess sufficient content knowledge in STEM (Breiner et al., 2012; Scherer, 2014; Thi To Khuyen et al., 2020) to facilitate learning in a way that learners are able to make sense of how the world around them works (Bybee, 2013; Scherer, 2014). Hence, exploring the knowledge, experiences, and practices of STEM teachers, as viewed in the lens of TPACK, is crucial in promoting better understanding of STEM education, and consequently contributing to the knowledge base of integrated STEM.

STEM Education in the Philippines

Just as in other countries, STEM education in the Philippines likewise focuses on increasing student enrolment to STEM programs, training of STEM teachers, and enhancing curriculum and instruction. It is noteworthy to mention that STEM in the Philippines may imply separate reference to each of the STEM disciplines – Science, Technology, Engineering, Mathematics, not as an integrated discipline. To attract and retain students to STEM programs, the Philippine government, through the Department of Science and Technology (DOST) offers several scholarships and financial grants to high school, undergraduate, and graduate STEM and STEM-related programs. The Philippine Science High School System (PISAY), for example, provides free high school education to all students under a Science-oriented curriculum. PISAY aims to establish a collaborative STEM ecosystem by "providing the architecture for cross-sector learning, offering STEM-rich learning environments" (Oliveros, 2021). The Department of Science and Technology-Science Education Institute (DOST-SEI), on the other hand, provides scholarships to undergraduate and graduate students taking STEM and STEM-related programs. The DOST-SEI also hosts programs to promote STEM to prospective students such as the science camp, Push4Science campaign, Science Explorer, among many others.

To enhance the capacity of STEM teachers, several private and government efforts have been in place offering a wide range of continuing professional education in the areas of STEM. The DOST-SEI for example, through the Project STAR (Science Teacher Academy for the Regions), offers a cluster of capacity-building activities to improve the quality of teaching among STEM teachers. Project STAR implements innovative STEM training and conducts activities that catalyze professional development for teachers such as awards and recognition, mentorship, and research. The DOST-SEI also hosts the InnoBox program, a nationwide search for the most innovative teaching and learning resources, to encourage teachers to be innovative, creative, and practical in teaching Science and Mathematics concepts.

The Philippine government also strides forward in STEM and STEM-related curriculum. The Department of Education, through the Enhanced Basic Education Act of 2013, lists STEM as among the academic tracks that students may choose in Senior High School (SHS). The SHS STEM helps better prepare the students for a STEM degree and their subsequent STEM career. The Commission on Higher Education (CHED) has included STEM research as one of its priority areas for research grants. In fact, the research project from which this article was culled from, was funded by the Commission.

Purposes of the Research

The study used the TPACK (technological pedagogical content knowledge) framework to determine and visualize the STEM teachers' experiences and practices. Specifically, the study addressed the following objectives: (1) Identify the teachers' pedagogical, assessment, and technology integration experiences and practices; (2) Map and model the teachers' traits, experiences, and practices in pedagogy, assessment, and technology integration; and (3) Validate the visual/model through experts' and teachers' review.

Methods

This study was undertaken as part of a state-funded research investigating the Philippine Higher Education STEM teachers' TPACK. Aimed at extracting and visualizing teachers' experiences and practices, we utilized exploratory, design and development research paradigms using both qualitative and quantitative approaches. The overall project involved 103 higher education institutions (HEIs) randomly chosen from a total of 2,299, from 14 out of the 17 regions of the Philippines. Three regions were excluded due to military conflict and terrorist threat in the areas, which will compromise the safety and security of field researchers. Moreover, the research team reached a consensus that since the three regions are very different from most of the regions in the country, the environment and experiences of higher education teachers in the areas deviate from the average and are considered rare or special cases.

The 103 HEI's include 46 public and 57 private institutions of higher learning, which were selected using stratified methods. The institution(s) selected: 1) include STEM programs in their curricular offerings; 2) is either clustered as SUC (State Universities and Colleges) or LUC (Local Universities and Colleges) levels 1 and 2; and 3) is accessible through public transportation. It should be noted that COE (Center of Excellence) and COD (Center of Development) institutions or also called research universities were excluded from the selection since they are considered extreme outliers and do not represent the environment of the average higher education institution in the Philippines. We categorized our procedure into five phases.

Phase 1: Data Collection

The main research project included all tenured teachers (n = 1,940) who handle STEM-related courses in identified institutions. All of them responded to a self-rating higher education Proficiency Indicator tool, the result of which is presented in a previous paper (Morales et al., 2020). From these original numbers, school representatives nominated teachers who they believe will meet the criteria set by the research team. Schedule and availability for post-conference interviews and classroom observation were also accounted for. This selection process generated 106 samples for teaching observation and interview with their respective Deans or Heads of college/department during the post-conference (a total of 22 school officials provided information in this study). This second layer of samples served as the principal source of information for this paper.

The data from these 106 sampled participants is sourced from a five-instrument document: 1) a Classroom Observation Rating Scale (a 48-item, 6-point Likert scale tool), 2) Classroom Observation Notes (includes questions clustered into the TPACK dimensions designed for qualitative observations), 3) TPACK interview protocol (6-item, main questions with corresponding probing questions clustered into themes), 4) technology integration checklist, and 5) assessment checklist. This pack was used by trained field researchers who were deployed through official school visits in the sample HEIs. School visit protocol included a courtesy call with a short interview with the officials/administrators; and the collection of signed consent forms before the activities (classroom observations, post-conference interviews), and other relevant information/documents (session guides, classroom activity guides, instructional materials).

Phases 2 & 3: Data Management and Coding

The data from rating scales and checklists were tallied, and consolidated; and descriptive statistics were used to analyze and interpret the results. Meanwhile, interviews and focus group discussions, which lasted on an average of an hour and were done in English or Filipino, were audio-taped, transcribed, and organized by assigned field researchers, since they are most familiar with the data, thus ensuring that no details were missed. Other forms of collected data were transformed by trained research assistants into digital forms through scanning and encoding. For data management purposes, we created a database with corresponding virtual folders per HEI where digital forms of the data gathered are stored.

The analysis of the qualitative data involved two layers. The first comprised three sub-groups of researchers tasked to analyze the data in three different aspects: pedagogy, assessment, and technology integration; and guided by the CHED's PSG for STEM programs and the standards of tertiary teaching (Morales et al., 2020). Since the collected data were already in digital form, we were able to maximize the aid of qualitative data analysis software (MAXQDA) to better facilitate the analysis process. Although digital, the initial content analysis was done manually through "open coding" by each sub-group with the assistance of the field researchers who were part of the data collection process. The sub-groups followed a systematic and replicable technique for compressing vast amounts of narration into fewer content categories following the explicit rules of coding that resulted in three coding frames, one for each group. These core codes were redefined in the succeeding phases of analysis. Then, we implemented "selective coding" (three iterative rounds of coding) to define the most significant higher-level codes and sort the lower-level codes created during the initial coding phase. We then hierarchically grouped the codes into concepts by sorting the codes into the 'parent codes and sub codes' for designing the 'code tree'. From the code tree, we categorized the concepts through relationship identification. Here, we created categories by grouping together similar concepts, which became our basis for the new theory structure. We established theoretical links between our devised categories forming three individual visuals.

Phase 4 & 5: Re-thematization and Three-Tier Validation

We extracted all attributes of each of the individual visuals for re-thematization that mapped all the attributes in the TPACK framework. The three individual visuals were deconstructed, sifted, charted, sorted and aligned in accordance with key TPACK dimensions and themes. We then mapped and interpreted the result of our re-thematization to provide a schematic diagram that defines concepts, creates typologies, finds associations, provides explanations, and identifies indicators that account for quality in Philippine higher STEM education.

The team conducted a three-tier validation process for all generated visuals. The first tier focused on experts validating the generated visuals (through round table discussion and small group discussions). For the second tier, purposely selected 113 STEM teachers (invited in a capability training program) afforded comments and suggestions for the visuals, which informed the revisions done soon after. The third tier featured the crafting of Lesson Exemplars (LEs - per specialization) by the participants and intense discussion conducted in a national forum with 125 STEM teachers, experts and school administrators. Their consolidated comments and reflections during the presentation of the visual capped the validation processes delivering the final visuals.

Results

This study presents the findings in three themes corresponding to the aforementioned objectives of this research.

Teachers' Pedagogical, Assessment, and Technological Integration Experiences and Practices

Through the lens of TPACK, three visualizations of teachers' pedagogical, assessment, technological integration experiences and practices emerged corresponding to the three sub-groups of the research team. The succeeding tables report the summary of codes for each of the three subgroups.

Table 1

Summarized Codes for Pedagogical Visualization

	Organizing Theme	Selected Codes/Basic Themes	Description or Organizing Theme
PEDAGOG ICAL MODEL	Institutional Pedagogical Culture	Planning the Pedagogical Processes (PK) "*I have to prepare myself to teach a lesson. Kailangan, as much as possible ma-test mo lahat ng mga possible options, or yun mga possible na pwedeng mangyari before you discuss* (I need to test possible options and scenarios that can happen before I discuss.)" Disseminating Pedagogical Processes (PK) "*nagpi-peer teaching kami* (we conduct peer teaching (for strategy or content))" Evaluating the Pedagogical Processes (PK) "*the result of the assessment would tell me if the topic has been understood or not… I would be able to decide whether to reteach a little before proceeding to the next* (topic)" Institutional Support to Pedagogical Processes (TPK) "*we attend conferences… this funded by the institution… then not only in teaching strategies even when it comes to development of skills*"	Refers to institutional practices that support the pedagogical process and requirements of teachers and staff. The model proposes an institutional mechanism in planning, disseminating, and evaluating pedagogical processes.

Teacher Pedagogical Character	Teacher acknowledges the diversity in teaching strategies (PCK) *"the need of one would be different from each other … the level of students are also highly diverse…* (students) *are highly diverse in terms of needs, in terms of intellectual capacity, and another one in preference of learning"* Teacher models learning (TPACK) *"we conduct pedagogical training… how to make good questions, art of questioning. We also have the 21st century learning teaching styles and the OBE.*	This pertains to the teachers' epistemological beliefs and pedagogical practices.
Employing STEM Appropriate Teaching Strategies	Employing Output-Based Learning (PK) "*we revised all the syllabi into OBEdized ones… we are after the learning outcomes… it is more performance based*" Employing Lecture Method [PK] "*we have to consider also that our courses are board courses, so we cannot get rid of the lecture discussion*" Employing Collaborative Learning (PK) "*I always adapt to collaborative learning…* [students] *share among themselves kung ano yung natutunan nila* [what they learned]… [it] *encourages maximum participation*" Eliciting prior knowledge (PK) "*you can't discuss a lesson without dealing with the previous lesson… it has an order to be followed for students to understand from simple to complex*" Strengthening learner's communication skills (TPK) "*may dinagdag na din kami na parang institutional course* [we added an institutional course]… *lahat ng programs mayroon kaming inilagay na advance technical communication* [we added advance technical communication for all programs]" Monitoring of Learners' Acquisition of Knowledge (PK) "*kapag yung klase talagang mababa, inuulit ko yung lesson* [if the class obtained low scores, I repeat the lesson]" Establishing a Mentoring Mechanism for Students (PCK) "*it is part of a mentoring program… even teachers have mentors*" Managing the classroom (TPACK) "*We have rules in the lab, before conducting* [classes]… *we have to secure safety measures*"	The pedagogical processes currently employed by the Philippine teachers in teaching STEM courses, primarily the teaching approaches and corresponding teaching techniques.
Outcomes of the Pedagogical Processes	Critical Thinking among Graduates (PK) "*to become critical thinkers… reflective thinkers… it is a conscious effort of the school to remind our teachers that we are supposed to develop students who think critically*" Performance in Licensure Examinations (TPACK) "*ang goal natin pag nagtuturo na tayo ay para makapasa ng board exam* [our goal when teaching is for our students to pass the board exam]… *useless kasi ang pagtuturo kung hindi ang goal is yung board exam* [it is useless to teach if the goal is not the board exam]" Employability of Graduates (TPACK) "*we incorporate trends that are in demand in our curriculum… para nag-graduate yung mga students namin, there is a higher rate of employability* [so when our students graduate, they have a higher employability rate]"	Attributes of the products of the pedagogical culture and processes

Note. Legend: CK (Content Knowledge), PK (Pedagogical Knowledge), TK (Technological Knowledge), PCK (Pedagogical Content Knowledge, TPK (Technological Pedagogical Knowledge), TCK (Technological Content Knowledge), TPCK (Technological Pedagogical Content Knowledge)

The pedagogical visualization (Table 1) reveals an interplay of the individual (Teacher Pedagogical Character) and the social (Institutional Pedagogical Culture) aspects, together with provisions for modality as informed by the notions of STEM teaching strategies and the outcomes of the pedagogical process. These interactions served as 'drivers' of the pedagogical decisions and practices of Filipino STEM faculty as would be seen in the final STEM visualization.

Table 2 shows the summary of the assessment practices of the sampled STEM teachers showcasing several organizing themes that emerged from the data which informed the visualization. Prior publication on this visual, which contains the detailed analysis of data on assessment practices, suggests that the best practices employed by these teachers from various higher education institutions in the Philippines were categorized according to the emerging themes (Sarmiento et al., 2020).

Table 2

Summarized Codes for Assessment Model

	Organizing Theme	Selected Codes/Basic Themes	Description or Organizing Theme
ASSESSMENT MODEL	Institutional affordances	Curriculum development (TPACK) "*we design and update the curriculum based on the actual needs of the people or the society*" Institutional identities (TPACK) "*lahat ng mga faculty under my department magkaroon sila ng mga faculty development that are being offered by different organizations and institutions na konektado kami* [faculty members from our department undergoes faculty development through organizations that we are connected with]*… when it comes to assessment normally, yung nagpo-provide po mga seminars is yung president po namin. Sila po yung naghahanap* [when it comes to assessment, it is usually provided by the president's office who search for such seminars]" Agency and empowerment (TPACK) "*my style is not like a military style… I empower them* [teachers] *if there are new things that they may integrate in their practice… they have academic freedom*"	The properties or facilities of educational institutions or an aspect of its environment and policies that aid the assessment process in STEM programs.
	Sustainability	Quality assurance (TPACK) "*we institutionalized evaluation that could help us monitor the quality of our teachers or the quality of instruction that our teachers provide*" Research undertakings (TPACK) "*I proposed a qualitative study on how my learner would want to learn physics… what kind of environment they want to be in…* [students] *have to take part in suggesting the outcomes within their level*" Policies and programs (TPACK) "*yung mga exam ng teachers, dumadaan muna sa program chairs* [teachers' exam must be submitted to the program chairs]*… may deadline kami ng at least mga 10 days before the first day of the exam* [we have a 10-day before exam policy for submission]*… then at least 6 working days before the first day of the exam dapat nai-submit na sa Dean* [then 6-days before the exam, it should be submitted to the Dean]*… and may policy din kami na if you're late in submitting, it will be charged against you. Babayaran mo through salary deduction* [we also have a policy that if a faculty submitted late, then he/she will shoulder the cost of reproduction]"	Efforts exerted to secure, maintain, and improve the quality of assessment processes in STEM programs.
	Ensuring equity	Gender sensitivity (PCK) "*whenever I make examples or even scenarios I always take into consideration the gender as well*" Monitoring and feedback (TPACK) "*magtatanong ka sa kanila para may feedback after ng discussion kung ano yung learning* [I ask them after discussion to solicit feedback about what they learnt]" Student performance, interest, and expression (Recognizing student differences) (TPACK) "*we must also consider the different types and backgrounds of learners… I observe this… we have different learners in engineering… some are visual, fast-learners, slow-learners, upgraded learner*"	Ensuring inclusion of all learners and making certain that each student has a fair and equal opportunity during the assessment process.
	Pursuing collaboration	Student-to-student (CK) "*we let them work as a group... we observe the results together and then they share what they understand or what they think*" Teacher-to-teacher (TPACK)	Dynamics that exist between the various key players in the

		"*upon the submission of the grades –prelim, midterms and finals – we have our deliberation. So, from there we could ask our faculty members how are their students… then, we derive strategies for new approaches that we* [can] *do*" Community involvement (PCK)/Involvement of other stakeholders (TPACK) "*we ensure that what we are teaching to our students is up-to-date… we invite from our industry partners… kung ano po yung mga ginagamit na applications or software para at least familiar yung mga students namin* [to discuss the applications and software that they use in the field to familiarize our students]"	assessment process.
	Utilizing modality	Tools and technology (TPK) "*we use means like social media, specially Facebook and other learning management system like Edmodo since those are free*" Assessment types (TPACK) "*for assessment tools… kapag may lab component* [if there is a laboratory component], *it is really a practical exam. In case* [of] *seminars and fieldtrip, we have the handbooks and the manuals, may mga pre-tests and post-tests depending on the type* [that contains pre-tests and post-tests depending on the topic]"	The variety of tools used and methods applied in the assessment process.

Note. Legend: CK (Content Knowledge), PK (Pedagogical Knowledge), TK (Technological Knowledge), PCK (Pedagogical Content Knowledge, TPK (Technological Pedagogical Knowledge), TCK (Technological Content Knowledge), TPCK (Technological Pedagogical Content Knowledge).

Finally, the technology integration visualization identifies institutional support and teacher technological knowledge as the major organizing themes. It entails infrastructures that would allow capacity building for teachers to deliver learning contents in various modalities in their respective contexts. Please see Table 3 for summarized codes.

Table 3

Summarized Codes for Technology Integration

	Organizing Theme	Selected Codes/Basic Themes	Description or Organizing Theme
TECHNOLOGY INTEGRATION MODEL	Institutional Support	Capacity building (TPACK) "*yung mga Microsoft Ambassadors in our department nagko-conduct po sila ng MS Office training* [Microsoft Ambassadors in our school conduct MS Office training]… *we also have Computer Literacy Program para ma-share po yung mga knowledge at mag-benefit yung community* [there is also a Computer Literacy Program to share knowledge that can benefit the community]" Architecture, design and system (TPK) "[we] *created a system, that will minimize and optimize the power consumption and process*" Quality of technology (TCK) "*we make sure that our tools and instruments are always calibrated and complete*"	Assistance in any form given by the institutions to enhance/equip teachers in integrating technology in their respective STEM disciplines.
	Teacher Technological Knowledge	Content driven (TCK) "*we make sure that our teachers relate the content of science to the community or make sure that science is relevant to the context of the students and the community*" Lesson structure (TCK) "*I structure my lesson part by part… I have a goal or time plan for my subject*"	Teachers' knowledge and understanding on the use of technology, and teachers' knowledge in integrating technology in their respective pedagogies and in various parts of the lesson delivery.

In summary, the coded responses of the participants emphasizing their experiences and practices exhibit six of the seven TPCK dimensions of the TPACK Model. Table 4 shows the frequency of occurrences of the TPCK dimensions in each of the models (pedagogical model, assessment model and technology integration model) presented in Tables 1, 2 and 3.

Table 4

Frequency of TPCK dimensions in each of the models

TPCK Dimensions	Pedagogical Model	Assessment Model	Technology Integration Model	Total
CK	0	1	0	1
PK	10	0	0	10
TK	0	0	0	0
TCK	0	0	3	3
TPK	2	2	2	4
PCK	2	2	0	4
TPCK	4	11	1	16
Total codes	18	16	6	38

Note. Legend: CK (Content Knowledge), PK (Pedagogical Knowledge), TK (Technological Knowledge), PCK (Pedagogical Content Knowledge, TPK (Technological Pedagogical Knowledge), TCK (Technological Content Knowledge), TPCK (Technological Pedagogical Content Knowledge)

Table 4 highlights the true nature of the derived pedagogical model, which emphasized the TPCK dimensions that highlight 'pedagogy', specifically, PK. The other models show the same attributes with assessment model emphasizing TPCK and technology integration model featuring TCK. It is worth noting that only the assessment model defines the majority of its coded responses as exhibiting the complete knowledge system denoting that teachers believe to showcase all knowledge systems during assessment processes. Such findings may be attributed to a balanced and distributed emphasis as well on TCK and TPK on all models that may have developed the entire TPCK system (Santos & Castro, 2021). Overall, TPCK dimension lodges 42% of the frequency of the coded teachers' experiences and practices based on a single knowledge dimension with no records for TK dimension.

Visualizing STEM Teachers' Experiences and Practices: The Philippine Higher Education Responsive Model (PHERM)

Re-thematization generated the initial responsive visualization of the major education domains to display chronology/sequence of ideas (Creswell, 2012) in terms of the TPACK dimensions (see Table 5). The attempt to map all attributes from the individual visuals into the TPACK framework did not capture all these attributes; hence, we included Outcomes-Based Education paradigm advocated by CHED in the re-thematization process to account for its strong focus on human resource development and future proofing of HEIs through quality assurance. Such has influenced the generation of new themes, which we labelled as variables and dimensions.

Four variables described as characteristic or quality, magnitude or quantity that can undertake transformations (Arias, 2012), were drawn which we identified as outcomes, drivers, institutional support, and processes. Based on the different characteristics and practices of STEM teachers in each of these variables, we characterized these variables as: drivers as the key factors and main considerations of STEM education; institutional support refers to the capabilities, forces, affordances, and resources that contribute to the success of STEM education; and processes as the mechanisms and progressions of STEM teachers and STEM education practices in the three learning domains.

Holistically, these variables express the experiences and practices of STEM teachers in terms of pedagogy, assessment, and technology integration. The outcomes are the envisioned product of the entire STEM programs in higher education that characterize the expected results of the Philippine STEM Education as; able to exhibit critical thinking skills, are successful in licensing, and are employable.

Furthermore, we found unique dimensions attributed to the three education domains in each of the aforementioned remaining variables. These themes are unique based on how they find context in the Philippine policy (OBE transition and typology-based quality assurance) and the TPACK framework, confirming a TPACK variant in the case of the Philippines, which we labelled as the Philippine higher education responsive model (Table 5 and Fig. 1).

Table 5

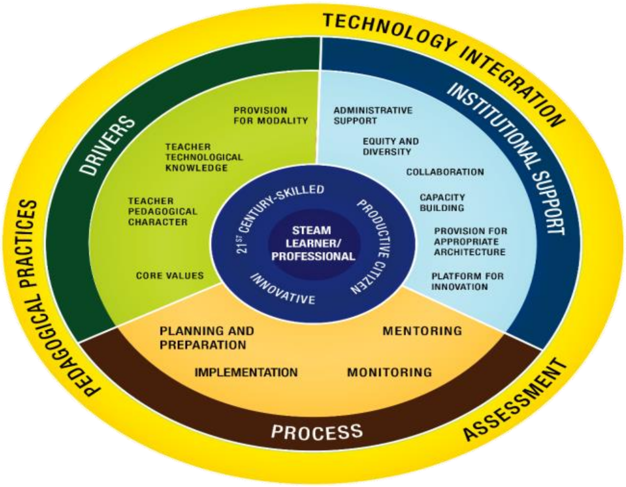
The Philippine Higher Education Responsive Model through the lens of TPACK

Outcomes	Drivers	Institutional Support	Processes
Critical Thinking Performance in Licensure Examination Employability	Pedagogical Model		
	Institutional Pedagogical Culture Teacher Pedagogical Character		Planning the Pedagogical Processes Employing STEM Appropriate Teaching Strategies Monitoring Learners' Acquisition of Knowledge Mentoring Mechanisms for Students Classroom Management
	Technology Integration		
	Teacher Technological Knowledge Lesson Structure Content-Driven Administrative Support Technological Architecture	Availability Affordability Appropriateness	Technological Architecture Capacity Building
	Assessment Model		
	TP Ensuring Equity Promoting Collaboration	Institutional Affordances Sustainability	Planning and Preparation Implementation Rating Reporting Reflection

Further abstraction and series of validations present the final visualization of STEM teachers' experiences and practices (Fig. 1).

Figure 1

The Philippine Higher Education Responsive Model (PHERM)



The final visual is a wheel-like image where the three subgroups are placed at the outermost layer. The four identified variables (outcomes, drivers, institutional support, and processes) surfaced as common among all the three sub-groups, with outcomes of producing STEM learners/professionals who are innovative, critical thinkers and productive citizens (represented in the innermost layers). The other variables are also represented (drivers, institutional support, and processes) with their corresponding dimensions.

Validation of the Model

The three-tier validation (Table 6) shows a bold transition of the visuals. Major changes and improvements are evident through the validation by experts who considered a future-proof system for STEM education. Several important elements sourced from the experts on the ground (STEM teachers) clinched the development of the visual for a more robust, appropriate, evidence-based, and responsive blueprint for Philippine STEM education.

Table 6

Three-Tier Validation of the Model

Model Constructs	Original Model	Tier 1 (Validation by Experts)	Tier 2 (113 Select STEAM faculty)	Tier 3 (125 Select STEAM faculty)
Outcomes	Quality STEM Education	Innovative STEM Learner/Professional Critical thinker Productive Citizen	Innovative STEAM Learner/Professional Critical thinker Productive Citizen	Innovative 21-st century-skilled Productive Citizen Inner Core: STEM Learner/Professional
Process	Planning and Preparation Implementation Monitoring Learning and Learners Mentoring	Planning and Preparation Implementation Monitoring Mentoring	Planning and Preparation Implementation Monitoring Mentoring	Planning and Preparation Implementation Monitoring Mentoring

Drivers	Institutional Pedagogical Character Teacher Pedagogical Character Teacher Technological Knowledge Administrative Support Utilizing Modality Ensuring Equity Promoting Collaboration	Provision for Modality Teacher Technological Knowledge Teacher Pedagogical Character	Provision for Modality Teacher Technological Knowledge Teacher Pedagogical Character	Provision for Modality Teacher Technological Knowledge Teacher Pedagogical Character Core Values
Institutional Support	Sustainability Affordances Appropriateness Affordability Availability	Capacity Building Provision for Appropriate Technology Administrative Support Collaboration Equity and Diversity	Capacity Building Provision for Appropriate Technology Administrative Support Collaboration Equity and Diversity	Administrative Support Equity and Diversity Collaboration Capacity Building Provision for Appropriate Architecture Platform for Innovation
Major Categories	Pedagogical Assessment Technology Integration	Pedagogical Practices Assessment Technology Integration	Pedagogical Practices Assessment Technology Integration	Pedagogical Practices Assessment Technology Integration

Other notes	Dots separate the three major categories	Dots were removed
		Improved color scheme
		With web to distinguish categories within constructs
		The same layering:
		• Outcomes
		• Major Constructs
		  ◦ Drivers
		  ◦ Institutional Support
		  ◦ Process
		• Major Categories
			Layering:
			Retained Outcomes, Major Constructs, and Major Categories
				No web
				Layering:
				Retained Outcomes, Major Constructs, and Major Categories

Additionally, a prominent observation points to the alignment of the visual to all the components of classroom observation protocol (COP) from where the grounding data for the visual was sourced. A coherent configuration of the model is also observed in all the parts of the Lesson Exemplar (LE) template including the Evaluation Rubric and in the implementation of LEs by identified STEM teachers.

Discussion

The study used the TPACK framework to determine and visualize the STEM teachers' experiences and practices. The deduced themes and constructs in each of the education domains (specifically in pedagogy), encompass the entirety of how STEM teachers view pedagogy in their respective disciplines. This view makes the list uniquely the pedagogical characterization of Filipino STEM teachers, which may not parallel how other countries characterize theirs (Mynbayeva et al., 2018). In the context of assessment, STEM teachers focus on assessment types and requisites of assessments in the classroom, and look at assessment in a holistic perspective deriving the many influences that affect its enactment (Dogan, 2013). In terms of technology integration, they exhibit practices that do not highlight the kinds/types of technology in the enactment of their lessons, but provide a semblance of holistic view of technology integration attuned to standards in terms of tools and technology types, resources, budgetary concerns, curriculum and guidelines (Harrell & Bynum, 2018). Their technology integration practices and experiences indicate novice-like integration practices due to the fact that technologically-influenced teaching paradigm in the respective institutions is in its birth (Blannin et al., 2021). In sum, among the three domains, a maturity in pedagogy and even in the assessment domain may be observed, but a novice level is observed in technology integration and weaving technology integration to assessment and pedagogical context.

The mapped traits, characteristics, and attributes of the STEM teachers in terms of education domains in the TPACK framework implies that a majority shows low engagement in the active use of technology in teaching their respective disciplines and a minority appropriately use technology with content in a suited pedagogy (McDonald, 2016). Specifically, none among the coded responses in all the models exhibit knowledge of technology (TK). Their degree of integration may be influenced by factors such as the availability of tools, their training and capability to weave technology integration in the discipline with appropriate pedagogy (Kumar & Daniel, 2016). This scenario has predicted the difficulty of the Philippine education system to migrate to full online emergency remote teaching during this pandemic, and a cling to modular teaching in the case of the participating institutions. Their geographic locale and traditions also situate them to using common materials accessible to them.

The findings denote that almost 50% of the coded experiences and practices of STEM teachers exhibit TPCK dimension. This result indicates STEM teacher quality and a positive outlook on teachers' competence in weaving the three education domains (pedagogy, technology and assessment) (Adipat, 2021). Furthermore, it may be inferred that there is a good TPACK lens on the enactment of STEM Education in higher and advanced learning in the Philippines. However, we may account for a novice acquisition of the entire TPC knowledge. The low engagement may be due to barriers and limitations in the affordances and support of their respective institutions (which we considered in crafting the unique themes to reinforce CHED's reform agenda (OBE and typology)). Technology integration for our STEM teachers is a young enterprise which may not index a high level of integration and may not be in sync in attaining Education 4.0 goals which somehow predicted the difficulty in shifting to online remote teaching in this time of pandemic.

Figure 1 shows the visualization of STEM teachers' experiences and practices that model the Philippine higher education. The labelled TPACK dimension of the mapped indicators in each of the variables and dimensions present a linear progression of proficiency of STEM teachers. They try to singly develop one knowledge construct of TPACK at a time, starting with a mastery of the content, then pedagogy, before integrating appropriate technology. Apparently, our education system developed STEM teachers profiled as discipline-specific who focus on singular knowledge of the TPACK framework. We note here their excellent practices and experiences in pedagogy and assessment despite them being situated in the rural areas. This result is indicative that the quality of their pedagogical and assessment competencies is not influenced by their being organic teachers in low tier universities and colleges (Gore et al., 2021). However, with their novice-like technology integration experiences and practices, it may take quite a while before they are able to blend all the knowledge systems in TPACK, which suggests upskilling to help them blend all the knowledge systems to successfully enact their STEM programs (Mishra & Koehler, 2006).

The visual's common variable (outcome) that transitioned twice in the validation process may imply that visions of the collective outcomes of Philippine STEM programs may be quite a blur yet as the Philippine OBE curriculum is just coming to maturation since its inception in 2012 (CHED, 2012). Hence, creating a niche for all STEM-related programs for a common vision of human resource is quite new in our education system that has provided quite a thought in identifying the ultimate program outcomes.

The three-tier validation provides a thorough process of how the theoretical experts (tenured teachers from COE's and CODs), and experts from the ground (tenured STEM teachers) evaluated, affirmed and polished the visual influenced by how they view such in their context to inform their practice. Inputs derived from the validation ensured a balance of expectations (theoretical) and the actual (real) scenario giving the visual a holistic attribute of systems approach (Tanuja, n.d.). Such approach is also evident in the framework alignment to the different aspects of the entire component of the classroom observation protocol (COP), the Lesson Exemplar template and Evaluation Rubric, deriving coherently designed LE's and associated outcomes of the implementation of LE's by STEM teachers informing the visual's success in instituting systems approach. All the sub-parts of each of the presented products and instruments are interconnected and have a specific alignment to a specific section in the model, making each part of each of the products mutually-dependent-sub-systems (Adcock et al., 2021) of the entire product. This consequently stages mutually dependent constructs of the visual or model in attaining the objectives of Philippine STEM education.

Identifying the current status of variables and dimensions of Philippine universities and colleges, and modelling STEM teachers' experiences and practices focus on major areas of concern that may need improvement to determine the root causes and derivatives of the low index of TPCK indicators. Such events may inform policies and guidelines to further seek enhancement, and consequently achieve the goals of higher education geared towards Education 4.0, pretty much similar to the intentions of Radović et al. (2021) who presented the mARC model as an education strategy to support learning. The responsive visual's uniqueness may be attributed to establishing a guide to draw technology, assessment and pedagogy suited to our condition and culture as Filipinos, which may influence how other countries may work on their own visuals to model their respective STEM education.

Future Research Direction

The modelling process espoused futuristic aims that may include transitioning Philippine higher education STEM programs into a future-proof 4IR-aligned program. Curricular revisions and transformations to include reconceiving their business ecosystem, redesigning their service architecture, providing a seamless stream of data for reconfiguration of curricula, infusing curriculum quality audit and embracing diverse forms of credentialing systems may do the trick. A progressive view may also hint on subjecting the visual to other layers of validation that will focus on other stakeholders to draw a more holistic visualization for STEM programs. We envision extending this endeavor to industry and community to provide the entire STEM education with a blueprint of the tertiary education of the country matched with an artificial intelligent system to navigate education, industry, and community providing valuable information to STEM professionals, students, and other stakeholders.

Lessons Learned

We only focused on determining the current visual for the Philippine STEM education through the experiences and practices of STEM teachers, and the other qualitative data that we have sourced. We did not consider the received curriculum which STEM students may provide. Replicate studies may look into the analysis of the tripartite structure (teachers-administrators-students) in higher education. Our analysis also sighted the important roles of external stakeholders (e.g. community partners, industry partners) and the influence of basic education. Further studies that would weave all these components and stakeholders might provide a more holistic picture in ensuring quality STEM education in the country.

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