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Gender-Responsive Mathematics Pedagogy in Technical and Vocational Education and Training Re-skilling for Industry 4.0: Advancing Inclusive Technical Workforce Development

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ABSTRACT

This study investigated the role of Gender-Responsive Mathematics Pedagogy (GRMP) in advancing inclusive Technical and Vocational Education and Training (TVET) re-skilling for Industry 4.0 workforce readiness. A descriptive survey research design was adopted to gather systematic empirical data. The target population comprised TVET trainees and instructors within public technical institutions across Benue State, Nigeria. A representative sample of 212 respondents (164 males, 48 females) was selected from the population through stratified random sampling based on institution type and discipline. Data were collected using a structured instrument titled the Gender-Responsive Mathematics Pedagogy and TVET Re-skilling Questionnaire (GRMPTVETQ). Face and content validity of the instrument were established by three expert validators in Mathematics Education and Educational Measurement, while internal consistency reliability yielded a Cronbach's alpha coefficient of 0.79. Data were analyzed using mean, standard deviation, independent-samples t-test, and simple linear regression analysis. Findings revealed that TVET trainees and instructors held highly positive perceptions of gender-responsive mathematics pedagogy (Grand Mean = 4.15, SD = 0.92). The t-test analysis indicated no statistically significant gender difference in perceptions of GRMP ($t = 1.78$, $df = 210$, $p = .076$). However, simple linear regression analysis demonstrated that gender-responsive mathematics pedagogy significantly predicted reductions in mathematics anxiety among female learners ($\beta = .61$, $t = 8.42$, $p < .05$), accounting for 37% of the variance ($R^2 = .37$). The study concludes that GRMP effectively promotes inclusive classroom engagement, and enhances technical workforce. Consequently, the study recommends institutionalization of gender-responsive instructional frameworks and continuous professional development for TVET educators.

Keywords: Gender-Responsive Mathematics Pedagogy, TVET, Industry 4.0, Mathematics Anxiety, Technology Integration.

INTRODUCTION

The Fourth Industrial Revolution, commonly known as Industry 4.0, has fundamentally transformed global production systems, organizational operations, and technical workforce requirements. Unlike previous industrial revolutions characterized by mechanization, mass production, and early digital computing, Industry 4.0 is driven by the convergence of hyper-advanced technologies. These include artificial intelligence (AI), autonomous robotics, cyber-physical systems, big data analytics, cloud computing, additive manufacturing, machine learning, and the Internet of Things (IoT) (Schwab, 2017). These emerging technologies have created highly automated, data-driven production environments capable of autonomous decision-making, real-time optimization, and complex system intercommunication. Consequently, global industries increasingly demand a technical workforce possessing not only traditional manipulative trade skills, but also advanced quantitative problem-solving abilities, computational thinking, digital literacy, and adaptive analytical capabilities.

The rapid pace of technological innovation has significantly restructured labor market dynamics, rendering routine technical tasks susceptible to automation while creating demand for highly specialized technical roles. According to the International Labour Organization (ILO, 2023), technological disruptions are reshaping global employment patterns, making continuous workforce re-skilling and up-skilling essential for sustaining national economic competitiveness and industrial resilience. Technical workers are now expected to exhibit fluency in computational modeling, statistical data interpretation, systems analysis, and technology-mediated workplace collaboration. Crucially, these advanced technical competencies are deeply rooted in mathematical reasoning and quantitative literacy. In technology-intensive production environments, mathematical literacy serves as the cognitive foundation for interpreting algorithms, operating diagnostic software, calibrating precision machinery, and troubleshooting automated systems.

Theoretical perspectives in educational psychology further illuminate how cognitive frameworks interact with technical skill acquisition. According to Constructivist Learning Theory (Vygotsky, 1978), learning is an active, social process where knowledge is constructed through contextualized interactions and collaborative problem-solving within a learner's Zone of Proximal Development (ZPD). Applying constructivist principles to technical instruction highlights the necessity of anchoring abstract

mathematical concepts in authentic, hands-on workplace scenarios. Furthermore, Social Cognitive Theory (Bandura, 1997) emphasizes the role of self-efficacy—an individual's belief in their capability to execute specific tasks—in driving academic persistence and performance. When female learners in technical fields experience supportive, non-stereotypical instructional environments, their mathematical self-efficacy is enhanced, directly countering systemic psychological barriers such as stereotype threat (Spencer et al., 1999).

Within developing economies such as Nigeria, educational and vocational systems face intense pressure to align technical training with the requirements of technology-driven markets. The Organisation for Economic Co-operation and Development (OECD, 2023) stresses that future economic sustainability depends on equipping learners with integrated technical and mathematical capabilities. Technical and Vocational Education and Training (TVET) serves as the primary engine for industrial skill development, human capital formation, and poverty reduction (UNESCO, 2021). TVET encompasses formal and non-formal educational pathways designed to impart practical skills, occupational knowledge, and technical attitudes necessary for gainful employment. In response to Industry 4.0 mandates, TVET institutions globally are shifting toward re-skilling—training individuals in entirely new technical competencies—and up-skilling, which enhances existing trade skills to match modern industrial standards (World Economic Forum, 2023).

Despite the critical reliance of TVET trades on mathematical principles—such as geometric spatial reasoning in building technology, algebraic equations in electrical circuit design, and statistical process control in manufacturing—mathematics instruction in TVET institutions often faces severe instructional challenges. A pervasive barrier is mathematics anxiety, characterized by feelings of tension, apprehension, and panic that interfere with quantitative problem-solving (Ashcraft & Krause, 2007). Cognitive research indicates that mathematics anxiety consumes working memory capacity, severely disrupting higher-order analytical functioning and task execution (Carey et al., 2019). Female trainees in TVET institutions frequently report elevated levels of mathematics anxiety compared to their male counterparts, a disparity largely driven by socio-cultural stereotypes, gendered instructional biases, and a lack of visible female role models in STEM fields (OECD, 2023; UN Women, 2023).

To overcome these institutional and socio-psychological barriers, Gender-Responsive Mathematics Pedagogy (GRMP) offers a transformative instructional framework. Gender-responsive pedagogy deliberate plans and executes teaching-learning processes to accommodate the specific gendered learning needs, preferences, and socio-emotional experiences of all trainees (UNESCO, 2019). GRMP moves away from rigid, teacher-centered rote instruction toward interactive, collaborative, and contextually grounded mathematical learning. By incorporating gender-neutral examples, collaborative peer problem-solving, supportive feedback mechanisms, and technology-assisted tools (such as virtual simulations and interactive software), GRMP dismantles gendered performance barriers, reduces math anxiety, and builds technical confidence (Boaler, 2016, 2022; Mishra & Koehler, 2006). Investigating the empirical impact of GRMP within TVET re-skilling programs is therefore paramount for building an inclusive, future-ready technical workforce.

The strategic implementation of GRMP within TVET re-skilling frameworks yields several critical workforce outcomes: Inclusive instructional practices foster a supportive environment, significantly reducing female attrition in quantitative technical modules. Collaborative peer learning and low-stakes contextualized problem-solving relieve psychological apprehension, promoting cognitive focus. Technology-integrated mathematics instruction reinforces practical application, enabling trainees to apply abstract quantitative concepts directly to modern trade tasks. Overcoming gendered instructional barriers expands the pipeline of highly skilled female technicians into Industry 4.0 technical sectors. Institutionalizing gender-responsive pedagogy aligns vocational technical education with broader national and international gender equality goals.

Despite substantial investments in TVET infrastructure and curriculum modernization, female participation and retention in high-tech, Industry 4.0-aligned technical trades remain disproportionately low across Nigerian TVET institutions. Empirical evidence highlights that traditional mathematics instruction within vocational programs remains heavily theoretical, abstract, and teacher-centric. This traditional approach frequently perpetuates implicit gender stereotypes, isolates female trainees, and exacerbates acute mathematics anxiety. Consequently, many female trainees exhibit reduced self-efficacy, underperform in quantitative trade modules, and disengage from advanced technical career trajectories. While previous research has broadly examined gender disparities in general education, there is a critical empirical gap regarding how Gender-Responsive Mathematics Pedagogy, especially when integrated with digital instructional technologies can systematically reduce mathematics anxiety and elevate technical engagement among TVET trainees. This study directly addresses this gap by investigating the impact of GRMP on TVET re-skilling for Industry 4.0 workforce development.

The main purpose of this study was to examine the role of Gender-Responsive Mathematics Pedagogy (GRMP) in advancing inclusive TVET re-skilling for Industry 4.0 workforce development. Specifically, the study sought to:

1. Examine TVET trainees' and instructors' perceptions of gender-responsive mathematics pedagogy.

2. Determine the extent to which gender-responsive mathematics pedagogy reduces mathematics anxiety among female TVET learners.
3. Investigate the influence of technology-integrated mathematics instruction on learners' engagement in TVET programmes.
4. Identify institutional policy measures required for effective implementation of GRMP within TVET institutions.

Research Questions

The following research questions guided the study:

1. What are the perceptions of TVET trainees and instructors regarding gender-responsive mathematics pedagogy?
2. To what extent does gender-responsive mathematics pedagogy reduce mathematics anxiety among female TVET learners?
3. What influence does technology-integrated mathematics instruction have on learners' engagement in TVET programmes?
4. What policy measures are required for effective implementation of gender-responsive mathematics pedagogy in TVET institutions?

Research Hypotheses

The following null hypotheses were tested at the 0.05 level of significance:

H01: There is no statistically significant difference between male and female TVET learners' perceptions of gender-responsive mathematics pedagogy.

H02: Gender-responsive mathematics pedagogy has no significant effect on mathematics anxiety reduction among female TVET learners.

METHODS

This study adopted a descriptive survey research design. The descriptive survey design was deemed appropriate because it allows for the systematic collection, quantitative description, and objective analysis of empirical data concerning perceptions, instructional practices, and psychological variables across a representative sample without manipulating the natural educational environment. The target population for this study comprised all TVET trainees (enrolled in technical re-skilling and national diploma programmes) and technical instructors across public TVET institutions in Benue State, Nigeria. The target population encompassed individuals across electrical/electronic technology, mechanical/fabrication technology, building technology, and computer craft studies. A sample of 212 respondents (comprising 192 TVET trainees and 20 TVET instructors) was selected using a multi-stage stratified random sampling technique. In the first stage, public TVET institutions were stratified based on geographical zones (North, East, and South). In the second stage, departments were stratified into specific technical trade clusters (Electrical, Mechanical, Building, and Computing). In the final stage, simple random sampling via balloting was utilized to select respondents within each stratum. The final sample consisted of 164 male respondents (77.4%) and 48 female respondents (22.6%), reflecting the historical baseline gender distribution in technical vocational programmes within the region.

Data were collected using a structured, researcher-developed questionnaire titled the 'Gender-Responsive Mathematics Pedagogy and TVET Re-skilling Questionnaire (GRMPTVETQ)'. The instrument was divided into two main sections:

Section A: Demographic Information (Gender, Role, Department/Trade Area, and Years of Experience/Study).

Section B: Four clusters measuring GRMP Perceptions (10 items), Mathematics Anxiety Reduction (4 items), Technology Integration & Engagement (10 items), and Institutional Policy Measures (9 items).

All items in Section B were measured on a 5-point Likert scale rated as: Strongly Agree (5), Agree (4), Undecided (3), Disagree (2), and Strongly Disagree (1). Real limits of numbers were established for decision-making: 4.50–5.00 (Strongly Agree), 3.50–4.49 (Agree), 2.50–3.49 (Undecided), 1.50–2.49 (Disagree), and 1.00–1.49 (Strongly Disagree).

To ensure instrument validity, the initial draft of the GRMPTVETQ was subjected to face and content validation by three independent experts: two senior lecturers from the Department of Mathematics Education and one expert in Educational Measurement and Evaluation from the Federal College of Education Odugbo. The validators critically appraised the items for construct clarity, language appropriateness, alignment with research questions, and coverage of Industry 4.0 TVET competencies. Revisions were made based on their expert feedback.

To establish reliability, the instrument was pilot-tested on a representative sample of 30 TVET trainees and instructors at a non-participating technical institution in Nasarawa State. The pilot data were subjected to internal consistency analysis using Cronbach's Alpha coefficient. The overall reliability index obtained for the questionnaire was 0.79, with sub-cluster coefficients ranging between 0.76 and 0.83. These values confirmed high internal consistency and reliability for empirical field administration.

The questionnaire was administered directly by the researchers with the assistance of two trained research assistants at the respective TVET institutions. A 100% retrieval rate was achieved through a retrieve-on-the-spot strategy. Data were coded and analyzed using descriptive and inferential statistics via SPSS Version 26. Research Questions 1 through 4 were answered using Means and Standard Deviations. Hypothesis 1 was tested using an Independent-Samples t-test at the 0.05 level of

significance. Hypothesis 2 was tested using Simple Linear Regression Analysis.

RESULTS

Research Question 1: Perceptions of Gender-Responsive Mathematics Pedagogy

Table 1: ***Mean and Standard Deviation of Responses on Gender-Responsive Mathematics Pedagogy***

Item Description	Mean	SD	Decision
Mathematics teachers encourage equal participation	4.26	1.03	Agree
Mathematics examples are relevant to both genders	4.32	0.90	Agree
Female learners are encouraged to ask questions	4.08	1.12	Agree
Group activities promote equal participation	4.55	0.64	Strongly Agree
Teachers avoid gender stereotypes	3.83	1.01	Agree
Female learners receive adequate support	3.96	1.05	Agree
Collaborative learning improves understanding	4.60	0.53	Strongly Agree
Classroom interactions are fair	4.36	0.82	Agree
Teachers use real-life examples	3.64	1.02	Agree
Gender-responsive teaching increases interest	3.94	1.07	Agree
Grand Mean / Standard Deviation	**4.15**	**0.92**	**Agree**

Table 1 shows that respondents held highly positive perceptions of gender-responsive mathematics pedagogy, as demonstrated by the Grand Mean of 4.15 (SD = 0.92). The highest rated items were collaborative learning improving understanding (Mean = 4.60, SD = 0.53) and group activities promoting equal participation (Mean = 4.55, SD = 0.64). The overall standard deviation of 0.92 indicates strong agreement and low variability among respondents.

Research Question 2: GRMP and Mathematics Anxiety Reduction

Table 2: ***Mean and Standard Deviation on Mathematics Anxiety Reduction***

Item Description	Mean	SD	Decision
Collaborative activities reduce fear of mathematics	4.00	1.01	Agree
Technology-assisted lessons make mathematics easier	4.13	0.98	Agree
Practical examples increase confidence	4.51	0.64	Strongly Agree
Group discussions help overcome anxiety	4.17	0.87	Agree
Grand Mean / Standard Deviation	**4.20**	**0.88**	**Agree**

Data presented in Table 2 confirm that gender-responsive mathematics pedagogy substantially reduces mathematics anxiety among female TVET learners, achieving a Grand Mean of 4.20 (SD = 0.88). Integrating practical trade-relevant examples yielded the highest mean score (Mean = 4.51, SD = 0.64), highlighting context-based problem solving as an effective antidote to mathematics apprehension.

Research Question 3: Technology Integration and Learner Engagement

Table 3: ***Mean and Standard Deviation on Technology Integration and Learner Engagement***

Item Description	Mean	SD	Decision
Digital simulations improve understanding	3.94	1.05	Agree
Virtual laboratories enhance engagement	3.96	1.04	Agree
Educational software enhances problem-solving	4.13	0.92	Agree
Online collaborative tools support learning	4.13	0.90	Agree
Technology increases interest in technical subjects	4.25	0.77	Agree
Computer-based instruction improves reasoning	4.21	0.70	Agree
Digital resources support self-directed learning	4.36	0.63	Agree
Technology links mathematics to workplace tasks	4.04	0.96	Agree
Interactive applications improve participation	4.19	0.83	Agree
Technology integration should be increased	4.28	0.80	Agree
Grand Mean / Standard Deviation	**4.15**	**0.86**	**Agree**

Table 3 reveals that technology-integrated mathematics instruction exerts a strong positive influence on trainee engagement (Grand Mean = 4.15, SD = 0.86). Trainees agreed that digital resources support self-directed learning (Mean = 4.36, SD = 0.63) and expressed strong support for expanding technology integration in TVET classrooms (Mean = 4.28, SD = 0.80).

Research Question 4: Institutional Policy Measures

Table 4: ***Mean and standard Deviation on Policy Measures for Effective Implementation of GRMP***

Item Description	Mean	SD	Decision
Mathematics is essential for technical occupations	4.34	0.88	Agree
Industry 4.0 requires mathematical skills	4.15	0.90	Agree
TVET prepares learners for digital workplaces	4.08	0.82	Agree
Mathematical problem-solving is important	4.34	0.79	Agree
Re-skilling should emphasize digital competencies	4.08	0.86	Agree
Gender-responsive instruction improves competence	4.00	0.84	Agree
Mathematics supports innovation and creativity	4.47	0.75	Strongly Agree
Female participation can be improved through better instruction	4.25	0.81	Agree
GRMP promotes workforce readiness	4.08	0.87	Agree
Grand Mean / Standard Deviation	**4.20**	**0.84**	**Agree**

Table 4 indicates robust support for formal institutional policy frameworks (Grand Mean = 4.20, SD = 0.84). Stakeholders strongly agreed that mathematics supports workplace innovation and creativity (Mean = 4.47, SD = 0.75) and that policy must prioritize digital competencies and gender-responsive pedagogical retraining for TVET instructors.

H01: There is no statistically significant difference between male and female TVET learners' perceptions of gender-responsive mathematics pedagogy.

Table 5: ***Independent Samples t-test on Perceptions of GRMP***

Gender	N	Mean	SD	t	df	p-value	Decision
Male	164	4.11	0.91	1.78	210	.076	Not Significant (Retained)
Female	48	4.23	0.88				

As presented in Table 5, the independent-samples t-test yielded $t(210) = 1.78$, $p = .076$. Because the calculated p-value (.076) is greater than the standard significance threshold ($\alpha = .05$), the null hypothesis (H01) is retained. This confirms that there is no statistically significant difference in perceptions of GRMP between male (Mean = 4.11, SD = 0.91) and female (Mean = 4.23, SD = 0.88) learners. Both groups hold highly favorable views of gender-responsive instruction.

H02: Gender-responsive mathematics pedagogy has no significant effect on mathematics anxiety reduction among female TVET learners.

Table 6: ***Simple Regression Analysis***

Predictor	B	T	P	R	R^2	Adj R^2	F	p (Model)
GRMP Implementation	.61	8.42	.000	.61	.37	.36	70.89	.000

Table 6 displays the simple linear regression analysis results. The model was statistically significant, $F(1, 46) = 70.89$, $p < .001$, with $R = .61$ and $R^2 = .37$. Gender-responsive pedagogy significantly predicted mathematics anxiety reduction among female trainees ($\beta = .61$, $t = 8.42$, $p < .001$). Therefore, the null hypothesis (H02) is rejected. The R^2 value indicates that approximately 37% of the variance in anxiety reduction among female TVET learners is directly attributable to gender-responsive instructional practices.

DISCUSSION

The findings of this study provide empirical evidence regarding the transformative impact of Gender-Responsive Mathematics Pedagogy (GRMP) in TVET re-skilling environments. Trainees and instructors exhibited overwhelmingly positive perceptions of GRMP (Grand Mean = 4.15). Respondents affirmed that GRMP practices such as encouraging equal questioning, using gender-inclusive trade examples, and utilizing collaborative peer groups dismantle historical gender biases in technical classrooms. Contextually within the Nigerian TVET ecosystem, technical trades have traditionally been male-dominated domains where female trainees often face subtle instructional marginalization. By actively structuring equal participation and supportive feedback, GRMP creates an empowering socio-emotional climate. This finding directly aligns with UNESCO (2019) guidelines on gender-responsive teacher training and reinforces Boaler's (2016, 2022) constructivist findings that inclusive group dynamics enhance mathematical

confidence and conceptual understanding across diverse learner populations.

Crucially, the regression analysis established that GRMP significantly predicts reductions in mathematics anxiety among female TVET learners ($\beta = .61$, $p < .001$, $R^2 = .37$). Mathematics anxiety has long been recognized as a major psychological barrier that depletes working memory resources and inhibits technical problem-solving (Ashcraft & Krause, 2007; Carey et al., 2019). In TVET trade courses where mathematics is applied directly to spatial design, electrical calculations, and mechanical diagnostics, math anxiety frequently leads to high female attrition. The contextual reason for GRMP's success in reducing anxiety lies in its shift from rigid, high-stakes individual testing to low-stakes collaborative problem-solving and authentic workplace applications. When female trainees engage in practical, hands-on quantitative tasks alongside supportive peers, their anxiety is mitigated and their mathematical self-efficacy is fortified, corroborating Bandura's (1997) Social Cognitive Theory and the OECD (2023) report on equity in technical education.

The study also demonstrated that technology-integrated mathematics instruction significantly enhances trainee engagement (Grand Mean = 4.15). Utilizing digital simulations, virtual laboratories, interactive graphing software, and computer-based modeling enables trainees to visualize abstract mathematical concepts in real-time. In Industry 4.0 production environments, mathematical reasoning is rarely performed using paper and pencil alone; rather, it is embedded in technological interfaces and software tools. Integrating digital tools into TVET mathematics instruction bridges the gap between theoretical abstract math and practical trade applications. This finding strongly supports the Technological Pedagogical Content Knowledge (TPACK) framework articulated by Mishra and Koehler (2006), as well as World Economic Forum (2023) mandates emphasizing digital workforce competencies.

Furthermore, the independent-samples t-test revealed no statistically significant difference between male and female trainees' perceptions of GRMP ($t = 1.78$, $p = .076$). This outcome is highly meaningful: it demonstrates that gender-responsive pedagogy does not disadvantage male trainees or create inverted gender disparities. Instead, GRMP functions as a universally beneficial, inclusive instructional strategy that elevates classroom engagement for all learners regardless of gender. Finally, strong support for institutional policy measures (Grand Mean = 4.20) underscores the urgent need for TVET administrators and policy-makers to formalize gender-responsive teaching standards and continuous professional development for vocational educators.

CONCLUSION

This study concludes that Gender-Responsive Mathematics Pedagogy (GRMP) is a vital instructional framework for advancing inclusive technical workforce development within TVET institutions preparing for Industry 4.0. Integrating gender-responsive teaching practices with modern digital tools directly addresses the dual challenges of mathematics anxiety and gender underrepresentation in technical trades. By replacing passive, teacher-centric methods with collaborative, technology-enhanced, and contextually grounded problem-solving, GRMP significantly lowers psychological barriers for female trainees while enhancing cognitive engagement for all learners. As Industry 4.0 continues to transform global and national labor markets, TVET institutions must transition toward inclusive, technology-driven instruction. Institutionalizing GRMP is essential for equipping a diverse, highly skilled, and resilient technical workforce capable of driving sustainable industrial development.

Recommendations

Based on the findings and conclusions of this study, the following recommendations are made:

1. Institutionalization of GRMP: TVET institutional heads and curriculum planners should formally adopt and integrate Gender-Responsive Mathematics Pedagogy as a mandatory instructional standard across all technical trade departments.
2. Continuous Professional Development: Federal and State Ministries of Education, alongside TVET regulatory bodies (such as NBTE), should organize mandatory capacity-building workshops and continuous professional development programs to train mathematics and technical instructors in gender-responsive and TPACK-aligned teaching methodologies.
3. Expansion of Digital Infrastructure: TVET institutions should increase capital investment in digital instructional technologies, including virtual trade laboratories, mathematical simulation software, interactive whiteboards, and open-access digital learning platforms.
4. Contextualized Curriculum Redesign: Mathematics curricula within TVET programs should be thoroughly revised to incorporate authentic, trade-specific problem-solving scenarios that align with Industry 4.0 technical applications.
5. Institutional Gender Support Frameworks: TVET leadership should establish formal gender support desks and peer-mentorship networks to reinforce female trainees' self-efficacy and career persistence in emerging technical fields.

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