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Developing primary student innovators through local wisdom and integrated learning

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ABSTRACT

Elementary science, technology, engineering, arts, and mathematics (STEAM) education often struggles with abstract, disconnected lessons, leading to students engaging in "making without learning". Addressing this gap, this study evaluated a novel STEAM learning package that uniquely integrates regional local wisdom with educational board games to enhance the innovator competencies and STEAM process knowledge of fifth-grade students. Employing a rigorous pretest-posttest quasi-experimental design, the study involved 240 students across four diverse school jurisdictions in Bangkok. To address common methodological limitations in educational research, a linear mixed model (LMM) was utilized to isolate the intervention's true effect from nested school contexts. The results demonstrated that the experimental group achieved significantly higher innovator competencies and STEAM knowledge compared to the control group. Crucially, the variance analysis revealed that school administrative structure and resources had a negligible impact on student outcomes. This underscores the study's strongest novelty: combining cultural heritage with gamification not only provides a highly effective pedagogical scaffold but also serves as an equitable instructional tool, successfully bridging the gap between abstract science and meaningful application across diverse educational environments.

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1. INTRODUCTION

The rapid transformation of the 21st-century global economy necessitates a fundamental shift in educational systems toward the cultivation of innovator competencies [1]. These competencies, encompassing problem framing, creative ideation, prototyping, evidence-based decision making, and collaboration, are essential for students to navigate and solve complex real-world challenges [2], [3]. While science, technology, engineering, arts, and mathematics (STEAM) education has emerged as an effective transdisciplinary approach to foster these skills, its practical implementation in elementary education frequently encounters significant instructional barriers [4]–[6]. In real classroom settings, severe time constraints and a lack of comprehensive instructional materials often reduce STEAM to disjointed, short-term craft projects. Consequently, students engage in "making without learning", where they build artifacts without comprehending the underlying scientific and mathematical principles or connecting abstract concepts to meaningful real-world contexts.

To address these instructional gaps, integrating local cultural heritage, such as traditional weaving or regional lantern making, offers a contextualized learning environment that connects abstract scientific concepts to the students' daily lives [7]–[10]. Utilizing indigenous knowledge in STEAM frameworks can support the reduction of material costs, stimulate cultural pride, and enhance students' creative thinking through the systematic application of the engineering design process (EDP) [11]–[14]. In addition to contextualized content, incorporating gamification and educational board games provides a concrete, "safe space" for trial and error that enhances intrinsic motivation and cognitive engagement [15]–[19]. To conceptualize how these instructional elements can be effectively combined, Figure 1 illustrates the proposed STEAM framework utilized in this study, demonstrating the structured pathway from the EDP and local wisdom integration to the cultivation of specific innovator competencies.

Despite the theoretical consensus on these benefits, previous empirical studies exhibit significant methodological and practical gaps. This research explicitly bridges these gaps through three distinct novelties: i) the functional integration of local wisdom to transform cultural heritage from a mere backdrop into core engineering challenges; ii) the implementation of a structured, gamified STEAM design using educational board games to simulate real-world constraints; and iii) the employment of a rigorous quasi-experimental design utilizing a linear mixed model (LMM). By treating the school context as a random effect, the LMM accurately isolates the true fixed effect of the STEAM intervention on innovator competencies, overcoming the limitations of analyses that fail to account for nested educational data. Ultimately, this study provides a highly adaptable instructional tool, and the overall relationship between this innovation, the statistical controls, and the targeted outcomes is summarized in the research conceptual framework, as shown in Figure 2.

Figure 1. The path to building innovators: a STEAM framework

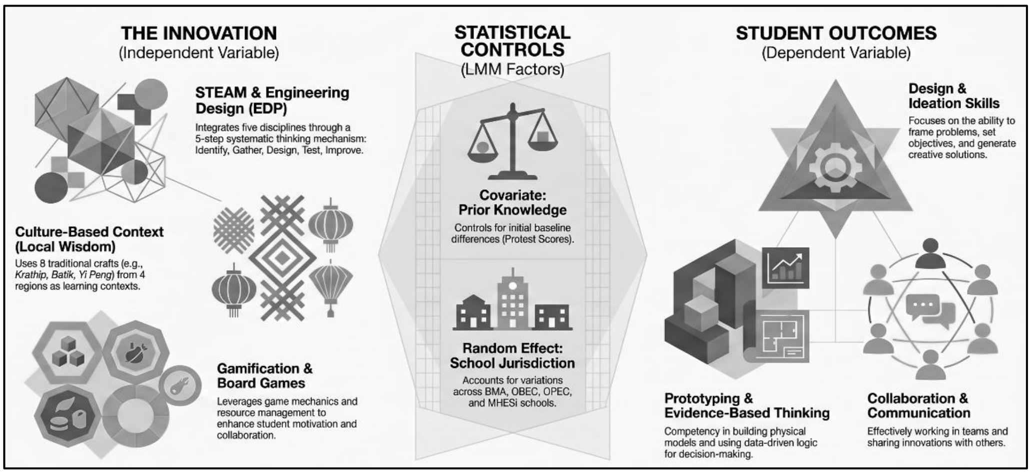

Figure 2. Research conceptual framework

To provide clear direction, this study aimed to develop and determine the efficiency of the STEAM learning package based on the 80/80 criteria, compare the outcomes between groups, and examine the influence of the school jurisdiction context. Accordingly, the research explicitly asks:

- What is the efficiency of the gamified package?
- Does the intervention significantly enhance STEAM process knowledge and innovator competencies compared to standard instruction?
- To what extent does school jurisdiction influence these outcomes?

Consequently, the explicit hypothesis tested is that students receiving the gamified STEAM local wisdom intervention will demonstrate significantly higher posttest knowledge and competencies compared to the control group (H1), rejecting the null hypothesis of no significant difference (H0), after controlling for pretest scores and the random effect of school jurisdictions.

2. METHOD

2.1. Research design and participants

This study employed a pretest-posttest control group quasi-experimental design to evaluate the efficacy of the developed instructional package. To ensure high internal validity and address previous criticisms regarding small sample sizes in exploratory educational research, a large-scale approach was adopted [20], [21]. The target population consisted of fifth-grade students in the Bangkok metropolitan area. A stratified cluster random sampling technique was utilized to ensure socioeconomic and administrative representativeness, dividing the sample into four distinct school jurisdictions: university demonstration, private, municipal, and public schools [22], [23]. The final sample comprised 240 students, evenly divided into an experimental group (n=120) and a control group (n=120). This total sample size substantially exceeds the minimum requirement for multilevel modeling to achieve sufficient statistical power and ensure robust parameter estimations [24], [25].

2.2. Instruments

Data acquisition was conducted using three primary instruments designed to capture both cognitive and behavioral outcomes. All instruments were systematically developed and underwent rigorous validity and reliability testing prior to the actual field experiment to ensure the robustness of the data collection process. Specifically, these tools included a specialized instructional package, a cognitive knowledge test, and a performance-based assessment rubric.

2.2.1. The STEAM learning activity package

The 18-period instructional package, integrating local wisdom and gamification, was evaluated for content validity by five subject-matter experts. The index of item-objective congruence (IOC) for all components ranged from 0.80 to 1.00, indicating an overall appropriateness rating at the highest level (M=4.63, SD=0.50). Figure 3 illustrates the practical implementation of this package, specifically showcasing the instructional sequence for the "Bo Sang umbrella" simulation, a prominent Northern Thai handicraft. As depicted in this designated process, students actively engage in the EDP by deconstructing the umbrella's mechanical frame and exploring the science of waterproof coatings through iterative trial and error.

2.2.2. STEAM process knowledge test

A 20-item multiple-choice assessment was specifically developed to measure students' understanding of scientific principles and local wisdom integration. Following a pilot test with a non-sample group, item analysis revealed an acceptable difficulty index (p) ranging from 0.35 to 0.75, alongside a good discrimination power (r) ranging from 0.28 to 0.65. The internal consistency of the entire test was calculated using the Kuder-Richardson formula (KR-20), yielding a high reliability coefficient of 0.84 [26], which confirms its statistical suitability for formal assessment.

2.2.3. Innovator competency rubric

A 5-dimension performance-based scoring rubric was utilized to evaluate students' competencies, including problem framing, prototyping, and evidence-based thinking. To address potential subjective bias in performance evaluation, the assessment systematically employed multiple independent raters. The inter-rater reliability, calculated between two independent experts evaluating a pilot sample, demonstrated a strong overall correlation coefficient of 0.88 (ranging from 0.85 to 0.92 across the five dimensions), thereby ensuring high consistency and objectivity in the scoring process [27]. A detailed summary of the key behavioral indicators required to achieve the highest performance level (level 4) across all five dimensions is provided in Table 1.

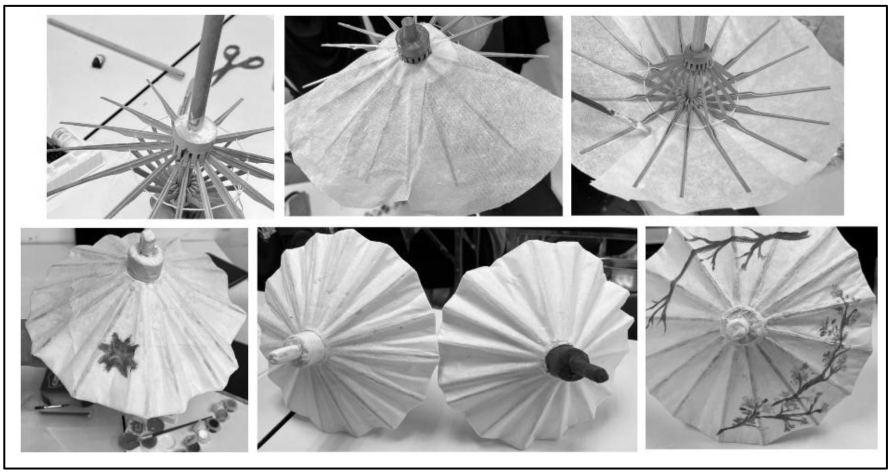

Figure 3. STEAM learning activity package: students engaging in the Bo Sang umbrella simulation activity

Table 1. Summary of innovator competency rubric (level 4 indicators)

Dimension	Key behavioral indicators (highest level-4 points)
IC1: problem framing	Clearly identifies users, goals, and constraints; writes problem statements consistent with the issue, and links to community context or local wisdom.
IC2: ideation and design creativity	Proposes at least two alternatives; selects an approach suitable for constraints with clear scientific/mathematical reasoning, and creates a novel piece of work.
IC3: prototyping and iteration	Constructs a complete model according to the draft; solves immediate problems during construction; significantly improves the work based on test results, and uses materials efficiently.
IC4: evidence-based thinking	Systematically plans tests; collects data in clear tables; draws correct conclusions, and uses data to explain improvement decisions reasonably.
IC5: collaboration and communication	Assigns clear roles; everyone participates actively; communicates test results and work steps clearly, sequentially, and interestingly.

2.3. Procedure and fidelity of implementation

To facilitate exact replication, the quasi-experiment was systematically conducted over an 18-period timeframe, with each period lasting 50 minutes. The implementation followed a structured three-step sequence where both groups first completed the pretest, followed by the experimental group receiving the gamified package while the control group received standard instruction, and finally, both groups completed the post-assessment. To ensure high fidelity of implementation and treatment consistency across the diverse school jurisdictions, all participating teachers underwent a standardized training workshop prior to the intervention. Furthermore, the researchers utilized observational checklists during random classroom visits to verify that the instructional delivery strictly adhered to the designated protocols for both groups, thereby ensuring equivalent instructional time (900 minutes) and effectively preventing treatment diffusion.

2.4. Data analysis

Preliminary analysis evaluated the innovation's efficiency using the E1/E2 formula against the standard 80/80 efficiency threshold. For inferential statistics, comprehensive data screening and assumption testing for multilevel modeling were conducted to ensure the statistical robustness of the subsequent analyses [28]. Subsequently, LMM was explicitly chosen over traditional analysis of variance (ANOVA) or ordinary least squares (OLS) regression because it effectively isolates the true intervention effect by statistically accounting for the non-independence of students nested within different school jurisdictions, which were treated as a random intercept [29]. By designating the treatment condition and pretest scores as fixed effects, the model extracts the intraclass correlation coefficient (ICC) to precisely evaluate the proportion of total variance in competencies attributable to the school context versus the instructional intervention itself [30].

3. RESULTS AND DISCUSSION

3.1. Results

This section systematically presents the empirical findings regarding the efficiency of the developed STEAM learning package and its subsequent impact on students' competencies. The narrative is explicitly structured to highlight key findings derived from both the preliminary descriptive statistics and the inferential LMM analysis. By sequentially addressing each research question, the results provide a comprehensive overview of the intervention's educational effectiveness.

3.1.1. Efficiency of the STEAM learning activity package

Preliminary analysis focused on validating the instructional quality of the developed materials prior to evaluating student outcomes. The formative (E1) and summative (E2) evaluations demonstrated process and product efficiencies of 84.99% and 81.85%, respectively. This 84.99/81.85 ratio successfully exceeds the predefined 80/80 threshold, confirming that the gamified STEAM package effectively facilitates continuous student engagement and yields high end-of-unit academic achievements.

3.1.2. Comparison of STEAM process knowledge and innovator competencies

Initial comparisons utilizing descriptive statistics revealed that while both groups started with comparable baseline knowledge, the experimental group demonstrated substantial post-intervention growth across all evaluated metrics. To provide a clear quantitative overview of these improvements, Table 2 summarizes the mean scores and standard deviations for both STEAM process knowledge and the specific dimensions of innovator competencies. These descriptive baseline metrics serve as the foundational data for the subsequent advanced inferential modeling.

To rigorously determine the intervention's true statistical impact while explicitly accounting for the nested nature of the gathered educational data, a LMM was employed. Table 3 details the comprehensive LMM analysis comparing overall innovator competencies between the two experimental conditions. This analytical approach ensures that the reported competency gains are directly attributable to the instructional package rather than preexisting structural differences among the schools.

Table 2. Descriptive statistics of STEAM process knowledge and innovator competencies

Variables	Experimental group (n=120)		Control group (n=120)	
	Mean	S.D.	Mean	S.D.
STEAM process knowledge (max=20)				
Pretest	8.76	1.05	9.34	1.37
Posttest	16.37	1.18	11.44	1.24
Innovator competencies (max=4 per dimension)				
IC1: problem framing	3.55	0.52	2.39	0.55
IC2: ideation and design creativity	3.58	0.47	2.38	0.48
IC3: prototyping and iteration	3.36	0.54	2.38	0.53
IC4: evidence-based thinking	3.46	0.49	2.30	0.46
IC5: collaboration and communication	3.42	0.51	2.45	0.52
Overall competency score (max=20)	17.37	1.94	11.90	1.86

Table 3. LMM analysis of innovator competency scores (N=240)

Source of variance	Estimate (*β*)	SE	*z*-value	*p*-value
Fixed effects				
Intercept	11.05	0.45	24.56	0.000*
Pretest score (covariate)	0.09	0.047	1.91	0.056
Group (ref=control)	5.49	0.12	45.75	0.000*
Random effects	Variance			
School jurisdiction	0.025			
Residual	0.780			

*Statistically significant at the 0.05 level

The LMM results indicate a highly significant treatment effect across the targeted learning outcomes. Controlling for initial pretest scores, the experimental group significantly outperformed the control group in overall innovator competencies ($\beta=5.49$, $p<0.001$). A parallel LMM analysis for STEAM process knowledge yielded a similarly significant positive instructional effect ($\beta=5.35$, $p<0.001$). To further contextualize these statistical findings, a detailed visual breakdown of the post-intervention performance across all five specific competency dimensions is illustrated in Figure 4.

As depicted in Figure 4, the systematic integration of local wisdom alongside the EDP comprehensively enhanced both students' cognitive understanding and their practical application skills. The experimental group achieved consistently high-performance scores across all metrics, ranging from 3.36 to 3.58 out of a maximum of 4.00. Notably, the most pronounced developmental improvements were specifically observed in the dimensions of ideation and design creativity (IC2) and evidence-based thinking (IC4), highlighting the package's effectiveness in fostering higher-order analytical skills.

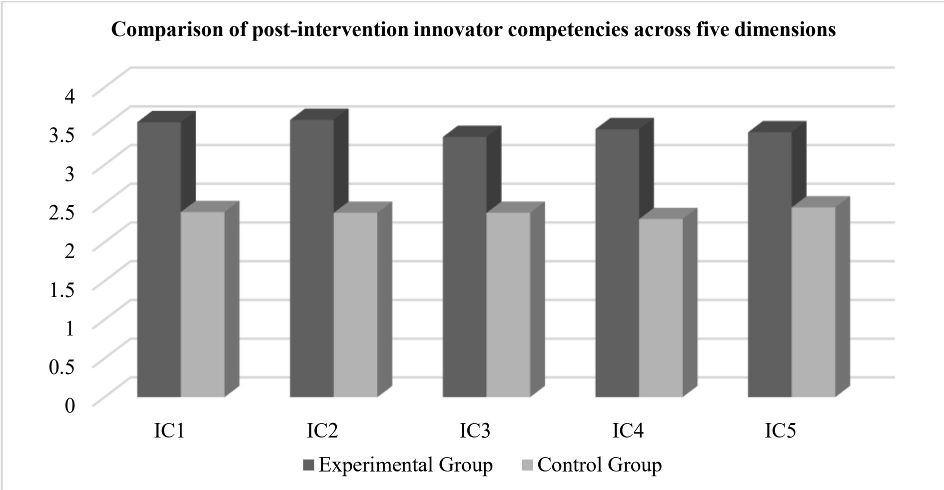

Figure 4. Comparison of post-intervention innovator competencies across five dimensions

3.1.3. Influence of school jurisdiction context (robustness check)

A critical component of this study was verifying whether the innovation's success depended on specific school resources or administrative types. The ICC was extracted from the random effects of the LMM to determine the variance attributable to the school jurisdiction. Table 4 presents these variance estimates to quantify the contextual influence.

Table 4. Variance estimates and ICC

Dependent variables	School variance	Residual variance	ICC	Context influence (%)
STEAM process knowledge	0.035	0.667	0.050	5.00
Innovator competencies	0.025	0.780	0.031	3.10

The findings highlight a remarkably low ICC across the evaluated domains. The school context accounted for merely 5.00% of the variance in STEAM process knowledge and a negligible 3.10% in overall innovator competencies. This minimal interpretation suggests that the clustering effect of the diverse school jurisdictions is practically non-existent. Consequently, the significant improvements in student outcomes are driven almost entirely by the instructional intervention itself, proving that the developed STEAM package is a highly equitable tool capable of delivering consistent results across diverse socioeconomic environments.

3.2. Discussion

The findings of this study indicate that integrating local wisdom and gamification within a STEAM framework provides a robust pedagogical scaffold for elementary learners. Beyond the quantitative competency gains observed, it is essential to consider the theoretical drivers that contributed to these outcomes. Specifically, the intervention appears to address the common instructional barrier of "making without learning" by anchoring abstract scientific principles to tangible cultural artifacts and interactive game mechanics. A pedagogical strategy aligned with contemporary frameworks for design and play [31].

3.2.1. Pedagogical mechanisms of local wisdom integration

The integration of local wisdom served as a robust cognitive scaffold, transforming abstract scientific principles into tangible, culturally relevant engineering challenges. For instance, during the "Bo Sang umbrella" simulation, students did not merely construct a craft; they deconstructed a technology that integrates multiple disciplines: science (waterproof coating properties), technology (local materials as protective tools), engineering (mechanical leverage and frame structural integrity), arts (aesthetic identity), and mathematics (geometric symmetry and surface area calculation). By anchoring learning in familiar regional crafts, the instruction provided a "meaningful context" that facilitated deep conceptual change, echoing the constructivist perspective that knowledge is most effectively constructed when linked to existing cultural frameworks [8], [32], [33]. This aligns with previous research highlighting that indigenous knowledge stimulates cultural pride while providing a cost-effective platform for complex inquiry [7], [11].

3.2.2. The role of gamification in fostering innovation

The inclusion of an educational board game provided a "safe space" for trial and error, which is psychologically critical for nurturing an innovator's mindset. The game mechanics, such as resource management (tokens) and randomized constraints (scenario cards), successfully simulated real-world engineering pressures. This fostered evidence-based thinking (IC4), as students were forced to make design decisions based on quantitative test results rather than intuition. The high engagement and "flow state" observed during the intervention support the meta-analytic findings [15], confirming that gamification significantly boosts intrinsic motivation and cognitive persistence in solving ill-structured problems.

3.2.3. Methodological implications for educational equity

A standout contribution of this study is the empirical evidence of the innovation's flexibility across diverse school jurisdictions [20], [21]. The exceptionally low (ICC of 3.10%) indicates that the school context accounted for a negligible fraction of the variance in student outcomes. This proves that the developed STEAM package is a highly equitable instructional tool. Unlike many educational innovations that perform well only in resource-rich environments, this package delivers consistent efficacy regardless of a school's administrative structure or socioeconomic status. This finding addresses the methodological gap identified by Margot and Kettler [6], providing a ready-to-use solution that reduces teacher workload and standardizes high-quality STEAM delivery.

3.2.4. Limitations and critical perspectives

Despite the positive outcomes, this study acknowledges limitations that warrant a critical interpretation. First, the 18-period duration (900 minutes), while effective for immediate competency development, restricts the assessment of long-term retention. Future research should employ longitudinal designs to verify if these innovator mindsets persist into higher grade levels. Second, while the use of multiple raters mitigated bias, performance-based assessments through rubrics are inherently sensitive to observer variance. Lastly, the study focused on regional handicrafts from four Thai regions; expanding the scope to include diverse global crafts or integrating high-tech digital components (microcontrollers or 3D printing) could further enhance the functional depth of the prototypes.

4. CONCLUSION

This study confirms that integrating local wisdom and educational board games within a STEAM framework provides a robust pedagogical scaffold for developing innovator competencies among elementary students. By successfully bridging the gap between theoretical scientific concepts and practical creative application, this gamified activity package offers a comprehensive solution to the challenge of disjointed learning in science education. Ultimately, the research achieved its primary objectives, demonstrating that the developed STEAM learning package possesses high efficiency with a process and product ratio that successfully exceeds standard instructional requirements.

Furthermore, the LMM analysis revealed that students engaging with the board game-integrated intervention achieved significantly higher STEAM process knowledge and innovator competencies across all five dimensions compared to those receiving standard instruction. A major methodological contribution of this research is the empirical validation of the innovation's consistency across diverse school jurisdictions, as the exceptionally low (ICC of 3.10%) proves that the efficacy of this STEAM package is independent of a school's administrative structure or socioeconomic resources. As an equitable, ready-to-use instructional tool, this gamified package significantly reduces teacher workload while standardizing an environment conducive to 21st-century skill development across varied educational settings.

Despite these positive outcomes, the study acknowledges specific limitations, including the lack of long-term retention data from the 18-period intervention and the inherent observational variance in rubric-based performance evaluations. To address these boundaries, future research should employ longitudinal designs to track student competency progress and mindset stability over extended periods. Additionally, subsequent iterations could explore integrating modern digital technologies, such as microcontrollers or 3D printing, with traditional local crafts and game mechanics to further enhance the functional depth of student prototypes.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
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E : Writing - Review & **E**diting
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Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study. For the primary school students participating in the quasi-experiment, written informed consent was explicitly obtained from their parents or legal guardians prior to their inclusion.

ETHICAL APPROVAL

The research related to human use has complied with all relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the Ethics and Research Standards Division, Srinakharinwirot University (Reference number: SWUEC/E-190/2565).

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [SW], upon reasonable request.

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