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Valuing pedagogies: Parents' affective, behavioral, and cognitive approaches to preschoolers' mathematical gameplay in virtual reality

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Abstract

This study aims to identify parental valuing pedagogy (VP) that supports their children's solving mathematical problems using a virtual reality application (app). To guide the development of this study and provide a framework for data analysis, this study proposes an initial gameplay model comprising three components: affect, behavior (social), and cognition (ABC). Three parent-child pairs solved 12 mathematical problems, and their interactions were fully recorded. Combining qualitative categories featuring rich descriptions with quantitative findings, this study identified detailed VPs within each of the ABC components. Quantitative analysis results reveal that the most significant VPs impacting child positive responses (PRs) are parental reasoning for knowledge and experimentation. The next two most significant VPs are in the behavioral aspect: parents' description of mysterious experiences and their initiation of particular actions. Affective VP does not significantly impact child responses, but may play a pervasive, yet hidden role. The app and computer usage also appear to play a role in parental utilization of VPs. The findings suggest that higher-order parental VPs are critically related to child PR during serious gameplay using an app.

Keywords: early childhood education, gamification, mathematical problem-solving, parent-child interaction

INTRODUCTION

Learning develops through social interaction, especially with more knowledgeable others (Vygotsky, 1978). Parents are typically the most important and capable learning partners for their children. Past research on parenting has predominantly focused on general attitudes or broad activity categories, which, while providing valuable insights and being predictive of various aspects of children's later development (Junge et al., 2021), offer limited detail. Detailed parenting strategies at the task level, however, remain relatively under-researched. Investigating these micro-level strategies can deepen our understanding of the daily practices that support children's development and may contribute to a more nuanced understanding of parenting beyond general styles.

The pedagogy in educational settings has long emphasized the cultivation of learners' affective, behavioral, and cognitive (ABC) development as learning and teaching objectives (Pierre & Oughton, 2007). The ABC framework can also serve as a general lens for understanding social learning across various tasks, including parent-child interactions focused on acquiring new skills (Gruber et al., 2022). Consequently, this ABC framework provides a suitable foundation for initiating the present line of research.

Technological advancements have transformed the landscape, artifacts, and infrastructure of learning and teaching. Empirical studies on task-level parenting, however, remain relatively scarce, despite the affective social learning model of ABC suggesting the relevance of related parental pedagogical approaches (Gruber et al., 2022). Consequently, there appears to be a gap in the literature concerning real-time parent-child interaction during problem-solving on technology-enhanced platforms. The purpose of this study, therefore, is to identify parents' valuing pedagogy (VP) that supports their children as they engage with serious mathematical games on a virtual reality application (Chiu & Zhu,

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Contribution to the literature

- Higher-order parental VP are related to child positive responses (PRs) during serious gameplay using an app.
- The most significant VP is parental reasoning for knowledge and experimentation, followed by parents' description of mysterious experiences and their initiation of particular actions.
- Affective valuing pedagogy (VPa) does not significantly impact child responses, but play a pervasive, hidden role.

2025). To guide this inquiry, this study employs an initial framework derived from the ABC model typically applied in formal education settings.

Parenting Styles or Strategies

Research consistently indicates that authoritative parenting is the most desirable style, particularly when compared to authoritarian, permissive (indulgent), and neglectful approaches. Authoritative parenting is generally associated with higher achievement, fewer problematic behaviors, and positive affective development in children (Ren et al., 2025). Authoritative parents are characterized by monitoring their children while also fostering open dialogue and allowing children's participation in decisions concerning important family matters and their own lives; in addition, cultural contexts can influence how these parenting practices relate to child adjustment outcomes within a complex system (Davidov, 2021). From this perspective, authoritative parenting can be viewed as a form of VP, possessing the potential to positively influence child development. Consequently, the specifics of detailed parent-child interactions merit closer examination.

For task-level parenting, the VP entails fostering effective interaction that promotes proximal development, recognizing the dynamic among the task, the parent, and the child. According to Vygotsky (1978), engaging in tasks within the zone of proximal development is crucial for developing competencies.

Valuing Pedagogies of ABC

Values and attitudes have been identified by the Organization for Economic Cooperation and Development (2019) as two major affective concepts pivotal to guiding future education. While attitudes are generally considered temporary, values are understood to develop over a prolonged period and are deeply connected to the cultural context in which an individual is embedded. Furthermore, values contribute to personal actions (Seah, 2019) and well-being (Hill et al., 2021).

VP encompasses approaches or strategies that contribute to learners' development, grounded in prolonged (either explicit or implicit) and embedded values (Chiu et al., 2025). Any natural pedagogy can be viewed as a value-laden enterprise, characterized by

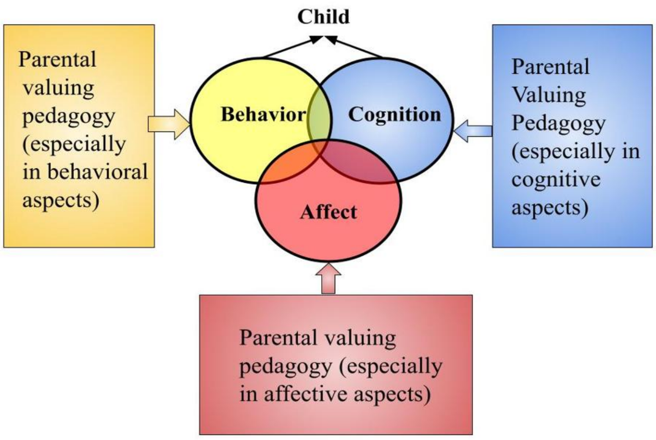

Figure 1. Initial model: Parental VP and child PRs in ABC (Source: Authors' own elaboration)

components of affective intentionality and social interaction (Clement & Dukes, 2019). VP can manifest broadly as general rules or principles (e.g., those articulated in curricula) or more specifically as explicit or implicit expressions utilized in supporting learners with a specific task (e.g., solving a problem). This study focuses on the latter, specific, task-oriented VPs.

Both value and VP typically encompass components of affect, behavior (often manifested as interaction), and cognition. Mathematics and science teachers emphasize ideological, sentimental, and sociological dimensions within their teaching practices (Bishop et al., 2006). In affect-focused mathematics teaching, teachers' VP can be categorized into the categories of affective, behavioral (social), and cognitive aspects, although teachers and students may place different emphases or have distinct concerns (Chiu & Seah, 2024). Likewise, for younger children, considerate parenting can be understood as originating with parental sensitivity, notice, awareness, or empathy/perspective taking (affect), followed by understanding and interpretation (cognition), and leading to prompt and appropriate responses (behavior) (Joussemet & Grolnick, 2022).

An Initial ABC Model of Parental VP and Child Responses During Co-Play on a Mathematical Game App

This study proposes an initial model that integrates ABC dimensions of parental VP and associated child PR

(**Figure 1**). The formation of this model is based on the following three rationales.

The ABC framework in traditional and e-learning contexts

In educational and instructional design, the ABC framework has long served as a basis for defining three major learning and teaching objectives (Pierre & Oughton, 2007). This framework is equally relevant to e-learning, where objectives can also be conceptualized through the ABC dimensions. For instance, playing a serious game involves two key processes: gameplay and learning (Koops & Hoevenaar, 2013; Koops et al., 2016). The learning process includes elements of sensing/feeling (affective), watching/doing (behavioral), and thinking (cognitive), which align directly with the components of the ABC framework.

Domain-specificity in parent-child ABC interactions

As previously noted, VP typically encompasses ABC components (Chiu & Seah, 2024). It logically follows that child PRs are also likely to manifest across these ABC dimensions. Furthermore, drawing upon the concept of domain-specificity or dimensional comparison (Chiu, 2017; Moller, 2024), the proposed model posits that VP and PR exhibit domain-specificity. This implies, for instance, that cognitive valuing pedagogy (VPc) primarily influences cognitive PR.

Structure of ABC

The next question is: How should the ABC be organized? The ABC framework applied to social learning suggests VPa may form the foundational base, with cognitive and behavioral VPs subsequently contributing to learners' growth and development (Gruber et al., 2022). This perspective aligns with the concept of natural pedagogy, which often describes value transmission as originating from an affective basis (Clement & Dukes, 2019).

Research Questions

1. What VPs do parents employ to support their children's PRs across the ABC dimensions when solving mathematical problems using an app?
2. What are the relationships between the parental VPs and children's PRs?

METHOD

Participants

The participants were three parent-child (or mother-daughter) pairs. The mothers were aged 31-40 years, and the daughters were 5 years old. The selection of 5-year-old children was deliberate. This age was chosen because the mathematical problems on the app were designed based on the grade-1 mathematics curriculum (see measures/the app). In Taiwan, 5-year-old children are typically one year from commencing formal schooling, which usually begins at age six. Being one year younger than the target age for this curriculum content, the children were expected to require maternal assistance in solving the problems.

The parents were recruited using snowball sampling, a method acknowledged for its convenience, effectiveness, and efficiency in identifying suitable participants (Woodley & Lockard, 2016). All mothers provided informed consent prior to their participation. The study received ethical approval from an institutional review board (NCCU-REC-202105-I030). The data obtained by the parent-child interaction and interview (fully recorded) are confidential. The content can be easily used to identify the participants, so the original data will not be open to the public.

Data Collection and Measures

This study adopted a primarily qualitative approach, supplemented by quantitative analysis of subsequently quantified qualitative data (Love & Corr, 2022). A trained research assistant (RA1) recruited participants and administered data collection in their homes. Data collection commenced with each mother-child pair playing the app. This gameplay session was fully recorded using both screen capture and facial video recording.

The app was developed using Unity and featured an API that connected to Google Sheets for recording gameplay data. It included 12 mathematical problems focusing on four major mathematical topics: data, geometry, pattern, and quantity (**Figure 2**). These problems were designed based on the grade-1 mathematics curriculum (Ministry of Education in Taiwan, 2018, p. 9), thereby establishing the difficulty level as appropriate for grade-1 children, who are typically six years old.

Data Analysis

Procedures

Data preparation and analysis of parent-child co-play involved three phases. First, the parent-child co-play videos were transcribed verbatim. Second, another trained research assistant (RA2) verified the transcripts, enhancing them with detailed descriptions of parent or child behaviors derived from the videos, and incorporating video clips as supporting evidence where relevant. Third, the project's principal investigator, who is also the first author of this paper, trained RA2 on the theoretical framework, coding scheme, and exemplary cases for coding the ABC aspects of parent-child interactions during problem-solving on the app.

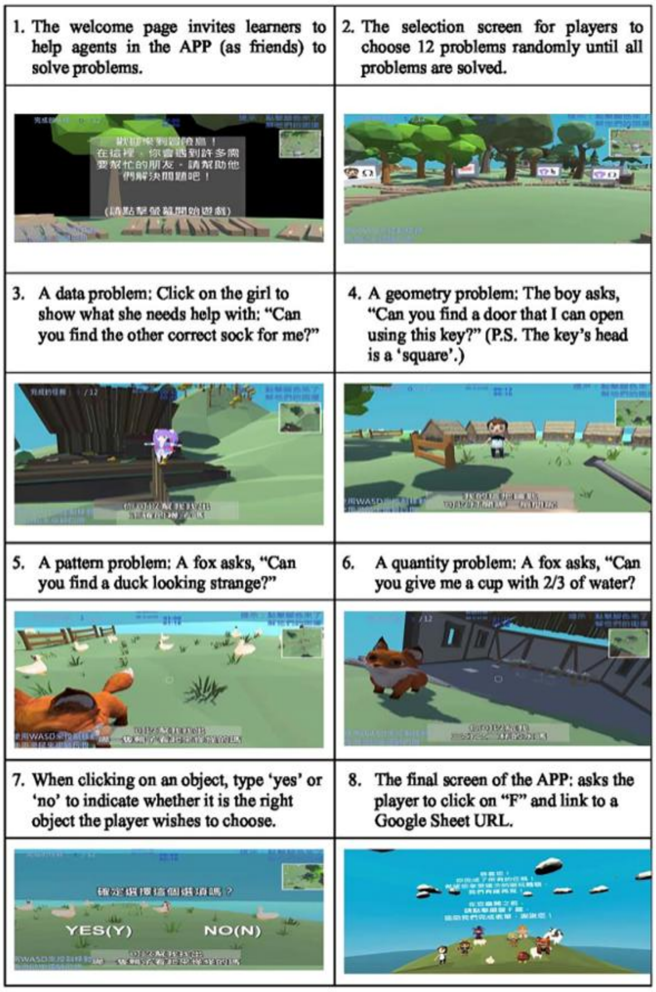

Figure 2. Example screen clips from the app (Source: Authors' own elaboration)

This training involved four sessions incorporating discussion, hands-on practice, and the use of tools to streamline data analysis (e.g., MS Word's comment and macro functions for transforming comments into a tabular format). This iterative process continued until the RA2 achieved consistent and accurate coding.

Coding Schemes

Parental VP: VPa encompasses parental expressions (e.g., verbal tone, voice modulation, and gestures) intended to foster their children's positive affect, motivation, and engagement during the problem-solving process. The targeted VPa might involve intuitive sense-making, a sense of control, and progression (Bishop et al., 2006), or even an acknowledgement of frustration. (Notably, parents in this study did not employ saliently negative VPa).

Behavioral (social or interactive) valuing pedagogy (VPb*)* pertains to interactions and connections with the external world, distinct from primarily internal cognitive or affective processes. VPb encompasses various elements, including what might be termed personal mysterious experiences, interpersonal interactions, and engagement with physical objects (e.g., the game, technology, machines), as well as connections to broader societal, cultural, or chronological contexts. For instance, mysterious experiences (such as appreciating the beauty of mathematics) are classified as behavioral or social because they involve a connection that extends beyond the individual to the external world.

VPc focuses on enhancing learners' competencies and achievements. Key pedagogical strategies for this purpose include imparting knowledge, guiding critical and creative thinking, facilitating strategy exploration, promoting problem-solving practice, encouraging experimentation with hypotheses, and fostering reasoning skills. Metacognitive processes, such as monitoring, planning, and knowledge retrieval, are also integral components of VPc.

Child PR: Affective positive responses (PRa) encompassed indicators such as confidence, concentration, and engagement, particularly evident when children were formulating or providing answers. Simple or vague responses, such as "yes," "this one," or "I don't know," were generally excluded. However, an utterance like "this one," when accompanied by a physical gesture (e.g., pointing with a finger) towards a specific item on the app screen, was coded as both PRa (indicating engagement or confidence in selection) and a behavioral positive response (PRb).

PRb were identified by observable actions demonstrating enthusiasm and eagerness. The coding of PRb centered on these physical actions or movements, which were not necessarily accompanied by oral expressions. For example, a child actively extending their hand in response to parental VP would be coded as PRb.

Cognitive positive responses (PRc) were identified by children's oral expressions that were hypothetical, meaningful, complex, or active, such as answers or questions, occurring in response to parental VP. For example, even when a parent stated, "You are correct," or indicated an intention to select a specific task on the app, a child might still exhibit PRc by asking, "Uh ... is that the one?" This type of response suggests active cognitive processing or independent verification by the child, rather than passive acceptance.

Quantifying procedures

The qualitative analysis was supplemented with quantitative methods to enable a more objective examination (Love & Corr, 2022). Each instance of parental VP and child PR was coded as "1" (denoting presence) based on the established coding scheme. The primary unit for coding, termed the "coding scope," was defined as a single interactional exchange between the mother and child. For example:

Parent: Is there anything less than half?

Table 1. Percentages and correlations of the codes

	Occurrence percentages				Correlations			
	All	Pair 1	Pair 2	Pair 3	PRa	PRb	PRc	PRm
Child PRs								
PRa	21.9%	**25.3%**	14.0%	20.8%				
PRb	27.8%	22.1%	**49.1%**	23.4%	0.103			
PRc	31.3%	30.5%	29.8%	**33.8%**	**-0.139**	**-0.117**		
PRm	63.9%	59.1%	**77.2%**	63.6%	**0.546**	**0.604**	**0.489**	
Parental VP								
VPam	47.6%	**54.5%**	29.8%	46.8%	-0.107	-0.023	0.049	-0.044
VPbm	53.1%	50.0%	**75.4%**	42.9%	-0.087	**0.251**	**-0.268**	-0.067
VPcm	59.7%	**64.9%**	57.9%	50.6%	0.106	-0.066	**0.266**	**0.190**
VPa1	18.8%	**21.4%**	10.5%	19.5%	-0.104	-0.020	0.060	-0.033
VPa2	30.9%	**33.1%**	22.8%	32.5%	-0.009	0.021	-0.013	0.000
VPa3	19.8%	**23.4%**	8.8%	20.8%	-0.115	-0.055	0.060	-0.062
VPb1	5.9%	2.6%	3.5%	**14.3%**	-0.026	-0.057	-0.074	-0.097
VPb2	21.2%	23.4%	**43.9%**	0.0%	-0.089	**0.172**	**-0.129**	-0.028
VPb3	38.9%	35.7%	**59.6%**	29.9%	-0.043	**0.221**	**-0.230**	-0.036
VPb4	1.4%	0.6%	1.8%	**2.6%**	0.009	**0.125**	-0.080	0.031
VPc1	12.5%	8.4%	15.8%	**18.2%**	-0.073	**-0.117**	0.085	-0.060
VPc2	53.1%	11.7%	19.3%	**22.1%**	0.021	0.068	0.033	0.076
VPc3	59.7%	**57.8%**	47.4%	13.0%	**0.177**	-0.063	**0.281**	**0.243**

Note. N (all codes) = 288; n (pair 1) = 77 (26.7 % = 77/288), n (pair 2) = 154 (53.3 %), & n (pair 3) = 57 (19.8 %); percentages represent the ratio of the occurrence (1 = yes & 0 = no) within each category; **the bold percentages** are the largest among the three pairs; **the bold underlined correlations** are significant at the 0.05 level; VPa1 = affirm answers; VPa2 = encourage continuing; VPa3 = respond with empathy and positivity; VPb1 = invite further action; VPb2 = instruct (gameplay/solution) methods; VPb3 = initiate/suggest action; VPb4 = describe mysterious experiences (including beauty of mathematics); VPc1 = explain gameplay rules or math concepts; VPc2 = verify answers or clarify misconceptions; VPc3 = reason for knowledge and experimentation; PRa = child positive affective responses; PRb = child positive behavioral responses; PRc = child positive cognitive responses; PRs = positive responses; PRm = mean of PRa–PRc; VPam = mean of VPa1–VPa3; VPbm = mean of VPb1–VPb4; VPcm = mean of VPc1–VPc3.

Child: Less than half, I saw it (vocal tone noted as happy).

These coding units were assigned sequential IDs within each pair (e.g., codeId/pair), serving as a proxy for the timing of VP occurrence. The total number of these units, both overall and for each pair 1-pair 3 individually, is presented in the notes accompanying Table 1. Following the comprehensive coding of all parent-child interactions, the subsequent step involved quantifying the themes identified within each ABC category. Themes exhibiting similar meanings were then integrated; for example, "explain key points in the game" and "explain game rules" were consolidated into "explain game rules (key points)".

RESULTS

Meanings and Manifestations of Parental VP

VPa, as identified in this study, manifested as positive parental attitudes aimed at fostering affiliation, rapport, and a desirable atmosphere while parents supported their children in solving mathematical problems using the app (Figure 2). Three primary categories of VPa were identified: affirming answers (VPa1), encouraging continuation (VPa2), and responding with empathy and positivity (VPa3).

VPb is characterized by parental use of language or actions intended to guide or elicit specific child behaviors. Four categories of VPb were identified: inviting further action (VPb1), instructing on answering methods (gameplay-specific) (VPb2), initiating or suggesting actions (VPb3), and describing a mysterious context (i.e., one extending beyond immediate social or fictional realms) to stimulate child actions (VPb4).

Parental VPc was categorized into three distinct types (VPc1-VPc3), representing a progression from foundational game comprehension to answer-focused interactions and, finally, to the promotion of higher-order reasoning. VPc1 centered on interpreting the rules for playing the games on the app. VPc2 addressed answer accuracy, wherein parents either verified their children's correct answers or clarified misconceptions when responses were incorrect or incomplete. VPc3 targeted higher-order thinking, involving parental guidance towards reasoning to foster a deeper understanding of knowledge and encourage experimentation with ideas.

Illustrative Cases of VPa, VPb, and VPc

Empathetic and encouraging VPa

Alice (pseudonym), the mother in pair 1, exemplifies the use of VPa. She consistently employed affirmation, encouragement, and empathy while supporting her daughter, Amy, as Amy played the games on the app. Notably, Amy exhibited the highest percentage of PRa (25.3%) among the three children (**Table 1**).

Alice demonstrated a high overall percentage of VPa (54.5%), with specific distributions for VPa1, VPa2, and VPa3 at 21.4%, 33.1%, and 23.4%, respectively. These values were notably higher than those of the mother in pair 2 (overall: 29.8%; VPa1: 10.5%, VPa2: 22.8%, VPa3: 8.8%) and also generally exceeded or were comparable to those of the mother in pair 3 (overall: 46.8%; VPa1: 19.5%, VPa2: 32.5%, VPa3: 20.8%) (**Table 1**). Furthermore, at the outset of gameplay, Alice focused on guiding Amy's engagement through intensive utilization of VPa, VPb, and VPc.

> Alice: Look! See this? It says it's a game, and it's one for grown-ups and little kids to play together. So let's play together, okay? Let's tap it! (VPa1, VPb3, and VPc1).
>
> Amy: (nods slightly) Mm-hmm! (0:02-0:14).

After completing five of the 12 games on the app, Amy assumed control of the mouse to play independently, rather than Alice operating it. Amy, however, experienced difficulty with mouse dexterity, likely because the adult-sized peripheral was too large for her as a preschooler. For instance, after Amy successfully selected the correct door for a shape-based key (as illustrated in part 4 in **Figure 2**), …

> Amy: Let's see more, and this one! (active vocal tone) (Pra and PRc).
>
> Alice: Then you got it right! (Returns to the selection screen, part 2 in **Figure 2**) So, which one do you want to open? (VPa1 and VPa3).
>
> (Amy continues to move the mouse to look around, but the screen appears laggy. She eventually hands the mouse back to her mother, seemingly seeking assistance.) (PRa; analyst note: Child exhibits positive affective response by actively attempting to control the mouse, despite the technical difficulty and eventual need for help).
>
> Alice: Mm-hmm! (takes the mouse back) Which other one do you want to see? (VPa2).
>
> Amy: I want to open this one (points to the screen) (PRa).
>
> Alice: Or do you want to open the ducky one? Is that it? (VPa2, VPc2, and VPc3).
>
> Amy: Mm-hmm (nods slightly; reaches for the mouse again).
>
> Alice: Okay! I'll help you move it (indicates the mouse; Alice takes the mouse from Amy's hand). Mm-hmm. Okay! You press it (VPa1-VPa3, VPb2, and VPc3).
>
> Amy: Press this one (attempts to press the mouse button herself) (PRa).
>
> Alice: Press the left one (VPb2).
>
> (Amy presses the right mouse button, an incorrect action).
>
> Alice: The left one, this one (VPa1 and VPb2).
>
> (Amy presses the left mouse button once).
>
> Alice: Good. Yes. Alright! Once you've pressed it, don't move it anymore. (Takes the mouse back) Let's pick a level. Pick this one, level six (from the 12 levels of the game on the app) (gives the mouse back to Amy) (VPa2, VPa3, and VPb2).
>
> (Amy takes the mouse) (9:54-10:37).

Alice demonstrates notable patience and support for Amy's desire to control the mouse. This approach can be interpreted as fostering Amy's autonomy while she navigates challenging tasks.

Directive and action-oriented VPb

Brenda, the mother in pair 2, provides a characteristic example of VPb in guiding her daughter, Betty, through problem-solving on the VR platform. Notably, Betty exhibited the highest percentage of PRb (49.1%), compared to Amy from pair 1 (22.1%) and the child from pair 3 (23.4%). A significant portion of Brenda's identified VP, 75.4%, was allocated to the behavioral aspect (see **Table 1**). Her VPb strategies, in descending order of frequency, included: initiating or suggesting actions (VPb3; 59.6%), instructing on gameplay or problem-solving methods (VPb2; 43.9%), inviting further action (VPb1; 3.5%), and describing mysterious experiences (VPb4; 1.8%). This pattern highlights Brenda's extensive and varied application of VPb. Brenda's utilization of VPb was evident from the very beginning of the gameplay session:

> Brenda: It says here there's an Adventure Island. And on this island, there are many friends who need help. Do you want to help them solve their problems? (Mom clicks on the screen. The child is sitting next to her, her eyes following the screen) (VPb3-VPb4).
>
> Betty: Yay! I love finding the answers! (PRab) …
>
> Brenda: Press Y for YES! Okay, next one! What's this problem then? Let me show you … What does

it say? "Can you help me find the correct sock?" Look at her feet. (The main character in this segment is a girl.) See? One of her feet doesn't have a sock on! (VPb2, VPb3, VPc1, and VPc3).

Betty: I think it's … Oh! Could it be this one? (child points at the screen) (PRb and PRc).

The aforementioned complex cognitive responses from Betty gradually diminished. Later in the session, Brenda's VPb became notably more frequent and appeared more effective in her interactions with Betty.

Brenda: Can I have one-third of the water? (mother uses the arrow keys to zoom the screen in further) (VPb3).

Betty: One-third, here. Is this one-third? (PRc).

Brenda: Two-thirds is more. One-third … one, two, three, that's a whole cup (VPc1, VPc2, and VPc3).

Betty: One-third (presses the left mouse button to confirm) (PRb).

Brenda: Press Y (VPb2).

Betty: (Presses Y) (PRb).

Brenda: Which ones haven't we done yet? (returns to the main page. Mother keeps the screen focused on the male character). Click on him (the boy agent on the screen of the app) (VPa2 and VPb3).

Betty: Click (the male agent) (PRb).

Brenda: Wait, let Mom try clicking! Something's blocking it. Let's turn it around and see … Okay! (VPb2 and VPb3).

Betty: Click (the male agent) (PRb) (7:04-8:04).

Integrated VP with a cognitive emphasis (VPc)

Coraline, the mother in pair 3, most frequently employed VPc (50.6%), relative to her use of VPa (46.8%) and VPb (42.9%) (**Table 1**). Indeed, Coraline demonstrated a relatively balanced distribution of VP use across VPa, VPb, and VPc, with percentages ranging from 42.9% to 50.6%. Correspondingly, her daughter, Cindy, exhibited the highest percentage of PRc (33.8%), compared to Betty from pair 2 (23.4%) and Amy from pair 1 (20.8%). Therefore, Coraline serves as a pertinent example of VPc utilization. This is evident from the initial stages of her gameplay with Cindy, during which Cindy initially displayed passive responses that were not coded as PR.

Coraline: So, just observe its shape and then which shape do you think it will be? (At this moment, mother has her right hand on the mouse. Her left hand points to a house on the screen, traces the shape along with the square key, and then points to the shape information appearing on the other houses) (VPc3).

Cindy: This one (the child, who originally had both hands cupping her chin, now points her right hand to one of the houses) (Pra and PRb).

Coraline: Okay, then let's click on it (YES and NO options subsequently appear on the screen). It says 'correct!' (mother claps once). You got it right! So, now let's play this one, okay? (VPa1, VPa2, VPa3, VPb3, and VPc3).

Cindy: Mm-hmm (nods simultaneously).

After approximately eight minutes of gameplay, Coraline's VP appeared to align more closely with Cindy's increasingly active responses, coinciding with an increase in Cindy's PR, particularly PRc. Coraline's VP utilization subsequently emphasized VPc, complemented by VPa and VPb, as illustrated in the following transcript excerpts.

Coraline: Okay, let's play this level next (the main agent is a boy). He's also asking, "Can you help me find which duck looks weird?" (mother zooms the screen in again so they can see the details of the ducks on the farm more clearly) (VPa2, VPb3, and VPc3).

Cindy: It's this one and this one again (the child extends her right hand and points to the ducks on the farm) (PRc).

Coraline: Mm-hmm (mother keeps scrolling on the screen) …

Cindy: Okay, then I'll click the one that's upside down (the child mimes flipping her body over) (Pra, PRb, and PRc) (8:06-8:27).

The preceding transcript excerpts illustrate an evolution in Coraline's VP utilization towards incorporating a more diverse spectrum of VPa, VPb, and VPc. Concurrently, Cindy's responses also progressed beyond primarily PRc, demonstrating a more complex pattern that often integrated PRa, PRb, and PRc.

Relationships Between Child PR and Parental VP

Overview of VP and PR frequencies and intercorrelations

Analysis of parent-child interactions identified 288 coding units associated with parental VP. Within these units, VPc was the most frequently observed (59.7%), followed by VPb (53.1%) and VPa (47.6%), in descending

Table 2. Regression results with parental VPs predicting child PRs

	Child PR							
Parental VP	**PRa**		**PRb**		**PRc**		**PRm**	
β	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
VPam	-0.117		-0.002		0.116		0.006	
VPbm	-0.044		**0.197**		**-0.192**		-0.026	
VPcm	0.058		0.001		**0.232**		**0.183**	
VPa1		-0.029		0.182		-0.063		0.056
VPa2		-0.011		0.030		0.077		0.062
VPa3		-0.122		-0.191		0.153		-0.090
VPb1		0.003		-0.054		-0.052		-0.065
VPb2		-0.040		0.087		-0.006		0.027
VPb3		0.010		**0.161**		**-0.159**		0.003
VPb4		0.031		**0.124**		-0.026		0.078
VPc1		-0.084		-0.096		0.093		-0.048
VPc2		0.003		0.067		0.060		0.082
VPc3		**0.165**		0.004		**0.290**		**0.283**
Pair 2	-0.061	-0.050	**0.246**	**0.245**	0.112	0.108	**0.189**	**0.192**
Pair 3	0.005	0.060	0.082	0.103	0.102	**0.175**	0.118	**0.210**
codeId/pair	0.125	0.118	0.121	0.127	0.117	0.099	**0.222**	**0.209**
R square	0.044	0.075	0.104	0.146	0.13	0.151	0.078	0.127
F (df1 = 6, df2 = 281)	**2.172**		**5.427**		**6.968**		**3.939**	
F (13, 274)		1.709		**3.589**		**3.745**		**3.072**

Note. We present the meanings of VPa/b/cVP#; ***the bold underlined numbers*** are significant at the 0.05 level; pair 2 (3) = dummy variables for pair 2 and pair 3 (control = pair 1); & CodeID/pair = code serial number (representing the time when the code occurs)

order of frequency (**Table 1**). The sum of these percentages exceeds 100%, indicating the co-occurrence of different VP types within single interactional units. Furthermore, child PRc exhibited negative correlations with both PRa and PRb. This finding suggests that when children displayed PRc, they tended to be less likely to concurrently exhibit PRa and PRb.

Predictors of PRa

Regression analysis was employed to identify significant parental VP types as predictors of child PRs, while controlling for inter-pair variability and the temporal sequence of VP occurrence within each pair (code sequence). Model 1 utilized aggregate scores (i.e., mean scores) for VPa, VPb, and VPc to predict PRa. Although model 1 achieved overall statistical significance ($F = 2.172$, $p < .05$), no individual VP type emerged as a significant predictor of PRa (**Table 2**).

Model 2 incorporated the 10 detailed VP subcategories (i.e., VPa1-VPa3, VPb1-VPb4, and VPc1-VPc3) as predictors of PRa. Within this model, PRa was significantly predicted by VPc3 ($\beta = 0.165$, $p < .05$). However, model 2 itself did not achieve overall statistical significance ($F = 1.709$, $p > .05$). This discrepancy might be attributable to the inclusion of numerous predictors, which can increase the probability of identifying significant individual predictors by chance.

Notably, a separate correlation analysis (**Table 1**) corroborated this finding, revealing a positive correlation between VPc3 and PRa ($r = 0.177$, $p < .05$). Taken together, these results suggest that higher-order cognitive guidance (VPc3) may be associated with children's positive affective responses (PRa).

Predictors of PRb

Child PRb were significantly predicted by the aggregate measure of VPb and by an indicator variable for pair 2 (model 3; $F = 5.427$, $p < .05$). Model 4, which examined the detailed VPb subcategories, yielded consistent findings ($F = 3.589$, $p < .05$), revealing that VPb3 (initiate/suggest action) and VPb4 (Describe mysterious experiences) were the specific VPb types significantly predicting children's PRb.

These regression findings are largely consistent with the correlation results presented in **Table 1**. However, two exceptions were noted in the correlation analysis: PRb exhibited a positive relationship with VPb2 and a negative relationship with VPc1, neither of which emerged as significant predictors in the regression models. This apparent discrepancy might be attributed to the nature of these relationships. It is plausible that VPb2 and VPc1 share only bivariate relationships with PRb; consequently, when other predictors were incorporated into the regression models (model 3 and model 4), the unique contributions of VPb2 and VPc1 to PRb variance may have diminished or become non-significant.

Predictors of PRc

Children's PRc is negatively predicted by VPb as a whole (i.e., VPbm, $\beta = -0.192$, $p < .05$) and positively predicted by VPcm (β = 0.232, p < .05; model 5, F = 6.968, p < .05). Model 6 finds more detailed VPs to predict PRc (F = 3.745, p < .05), with VPb3 (initiate/suggest action) negatively predicting PRc (β = -0.159, p < .05) and VPc3 positively (β = 0.290, p < .05). Correlation results are almost the same as regression analysis results, with the exception that VPb2 is a negative correlate (r = -0.129, p < .05). In model 6, pair 3 is also a positive predictor, a result consistent with the percentage result (**Table 1**) and the section of pair 3 as a typical example of VPc.

Children's PRc were negatively predicted by the aggregate measure of VPb (VPbm; β = -0.192, p < .05) and positively predicted by the aggregate measure of VPc (VPcm; β = 0.232, p < .05) in model 5 (F = 6.968, p < .05). Model 6, which examined the detailed VP subcategories, identified VPb3 (initiate/suggest action) as a negative predictor of PRc (β = -0.159, p < .05) and VPc3 (Higher-order cognitive guidance) as a positive predictor (β = 0.290, p < .05); this overall model was also significant (F = 3.745, p < .05).

The correlation analysis yielded results largely consistent with the regression findings, with the primary exception being a negative correlation between VPb2 and PRc (r = -0.129, p < .05), which was not a significant predictor in the regression. Furthermore, in model 6, an indicator variable for pair 3 also emerged as a positive predictor of PRc. This finding aligns with the descriptive statistics (see **Table 1**) and the qualitative illustration of pair 3 as a characteristic example of VPc utilization.

Collectively, these findings suggest that PRc is primarily fostered by VPc, particularly its most higher-order component (VPc3). In contrast, VPb appears to exert an opposing influence on PRc, potentially hindering its occurrence when VPb strategies are prominent.

Predictors of mean positive responses (PRm)

The mean scores of child PRs across the three domains (PRa, PRb, and PRc), hereafter referred to as PRm, were positively predicted by the aggregate measure of VPc (VPcm; β = 0.183, p < .05), an indicator variable for pair 2 (whose mother was a characteristic user of VPb), and a variable representing later stages of gameplay in model 7 (F = 3.939, p < .05). Model 8, which controlled for indicator variables for pair 2 and pair 3, as well as later gameplay, revealed VPc3 as the sole significant VP predictor, exerting a positive influence on PRm (β = 0.283, p < .05; F = 3.072, p < .05).

Correlation results find similar patterns, with only VPcm (r = 0.190) and VPc3 (0.243) as significant correlates (p < .05; **Table 1**). The picture appears to be that parental VPc (especially higher order VPc, i.e., VPc2) is the critical predictor of child PR.

Correlation analysis revealed similar patterns, with only the aggregate measure of VPc (VPcm; r = 0.190, p < .05) and VPc3 (r = 0.243, p < .05) emerging as significant correlates of PRm (see **Table 1**). Collectively, these findings suggest that parental VPc, particularly its higher-order component VPc3, is a critical predictor of overall child positive responses (PRm).

DISCUSSION AND CONCLUSIONS

Interpreting Parental VP Across Affective, Behavioral, and Cognitive Dimensions

This study identified specific parental VP strategies employed to support children's mathematical problem-solving during VR gameplay. The derived VP categories align with the predetermined ABC framework, which was informed by relevant literature on values, gamification, general education, and parenting (Chiu & Seah, 2024; Gruber et al., 2022; Koops et al., 2016; Pierre & Oughton, 2007). Collectively, the identified VPs can be broadly characterized as consistent with authoritative parenting principles (Ren et al., 2025). This parenting style is typically interactive, featuring extensive dialogue, scaffolding, and acceptance, all aimed at facilitating successful problem-solving.

The integration of rich qualitative descriptions with quantitative findings (Love & Corr, 2022) facilitates a more comprehensive understanding of the nature and nuances of the identified VP strategies, their interrelationships, and their connections to children's PR across the three ABC dimensions. This understanding is further elaborated upon and contextualized through engagement with relevant literature in the subsequent discussion.

VPa

VPa encompasses strategies related to answers (VPa1) and the problem-solving process (VPa2), both of which are delivered with empathy and positivity (VPa3). The former two subcategories (VPa1 and VPa2) align with critical components of mathematical problem-solving: achieving correct answers/solutions and navigating the solution process (DiNapoli & Miller, 2022). The latter subcategory (VPa3) underscores the importance of cultivating a warm and supportive atmosphere. This emphasis resonates with findings from formal school settings, where teacher empathy in fostering such an environment has been shown to positively impact students' well-being and sense of belonging (Cai et al., 2023).

Quantitative analyses revealed only one significant correlation and predictor for children's PRa: the higher-order VPc, VPc3 (see **Table 1** and **Table 2**). Surprisingly, and contrary to initial expectations regarding domain-specificity (Moller, 2024; **Figure 1**), no VPa subcategory significantly predicted PRa; instead, a VPc component emerged as influential. This unexpected finding suggests, however, that engaging children with higher-order cognitive guidance (VPc3) may indirectly foster positive affective outcomes, such as perseverance (cf. DiNapoli & Miller, 2022).

VPb

Parental VPb is primarily directed at encouraging children to act or engage in interaction. These strategies can be conceptualized along a continuum from less to more creative (or imaginative) engagement. Parental VPb encompasses inviting children to undertake further action, instructing on gameplay or solution methods/strategies, initiating or suggesting new actions, and describing 'mysterious experiences' (which may involve invoking a broader, imaginative community or highlighting the aesthetic appeal of mathematics). The former three VPb types resemble direct instruction, a well-established pedagogical approach in formal educational settings (Chiu & Whitebread, 2011). The latter type (describing mysterious experiences) aims to cultivate a more social atmosphere conducive to collective, supportive, and altruistic actions (Bishop et al., 2006; Chiu & Seah, 2024).

Children's PRb were positively predicted by overall VPb, and specifically by VPb3 (initiate/suggest action) and VPb4 (Describe mysterious experiences) (model 3 and model 4; **Table 2**). Correlation analysis also indicated a positive association with VPb2 (instruct gameplay/solution methods). These findings suggest not only domain-specificity in the behavioral dimension but also that more imaginative or higher-order VPb strategies (particularly VPb3 and VPb4) are effective in eliciting children's positive behaviors during gameplay. Given that imagination is a form of higher-order thinking, this result resonates with research demonstrating the effectiveness of creative pedagogy in teaching problem-based higher-order thinking skills in science (Affandy et al., 2024). The current study extends these insights by highlighting the potential impact of such creative parental approaches on children's behavioral engagement.

VPc

Parental VPc centers on providing information and facilitating mental processing to support children's successful problem-solving. The identified VPc subcategories can be conceptualized as a progression from lower- to higher-order cognitive guidance: explaining gameplay rules or mathematical concepts (VPc1), verifying answers or clarifying misconceptions (VPc2), and promoting reasoning for knowledge acquisition and experimentation (VPc3). This VPc1-VPc3 sequence aligns with the general framework and strategies of information processing theories, which typically involve stages from decoding (comprehension) and evaluation (monitoring) to elaboration (Fox, 2009).

Quantitative analysis revealed that children's PRc were negatively predicted by overall VPb (VPbm) and specifically by VPb3 (initiate/suggest action), while being positively predicted by overall VPc (VPcm) and specifically by VPc3 (higher-order cognitive guidance) (model 5 and model 6; **Table 2**). These findings suggest two key interpretations: first, VPb and VPc may exert somewhat opposing influences on child cognitive responses, potentially reflecting domain-specificity (Moller, 2024); second, parental higher-order cognitive scaffolding (particularly VPc3) plays a significant role. This latter point may further relate to underlying parental characteristics such as executive function and verbal ability (St. John et al., 2018).

Interaction of Parental VP, Child PR, and the VR App

Certain identified parental VP strategies appeared to be influenced by or interact with the VR app. Regarding VPa, Alice (pair 1) demonstrated a notable example by actively permitting Amy to attempt using the mouse, despite Amy's lack of proficiency. Alice's willingness to allow Amy to engage with a task that was slightly beyond her immediate capabilities, even if resulting in initial failure, seemed to foster a positive dynamic. This approach facilitated Amy's engagement with challenging tasks, was characterized by parental affective support, and encouraged Amy to actively confront these challenges. Regarding VPb, many observed parental behaviors were directly related to navigating or interacting with the app or computer. For instance, Brenda (pair 2) utilized VPb when she "use[d] the arrow keys to zoom the screen in further." This type of VPb, in turn, often linked to child PRb, as exemplified by Betty's (pair 2) action of "press[ing] the left mouse button to confirm." VPc frequently co-occurs with a broader spectrum of both parental VP strategies and child PR types. For instance, an utterance by Coraline coded as VPc3 (e.g., "Okay, let's play this level next … He's also asking … [mother zooms the screen in again so they can see the details of the ducks on the farm more clearly]") was often simultaneously coded for VPa2 and VPb3, suggesting an integration of cognitive guidance with affective and behavioral support. Correspondingly, Cindy's subsequent response (e.g., "Okay, then I'll click the one that's upside down [the child mimes flipping her body over]") often exemplified a multifaceted positive reaction, coded as PRa, PRb, and PRc.

The findings suggest that engagement with the app and computer plays a notable role in shaping parental VP utilization. Parents are confronted with a dual task: managing the mathematical problem-solving aspects of the serious game while simultaneously navigating the technological tools. This situation is analogous to that in formal educational settings, where teachers require technology, pedagogy, and content knowledge for effective teaching (Tondeur et al., 2020).

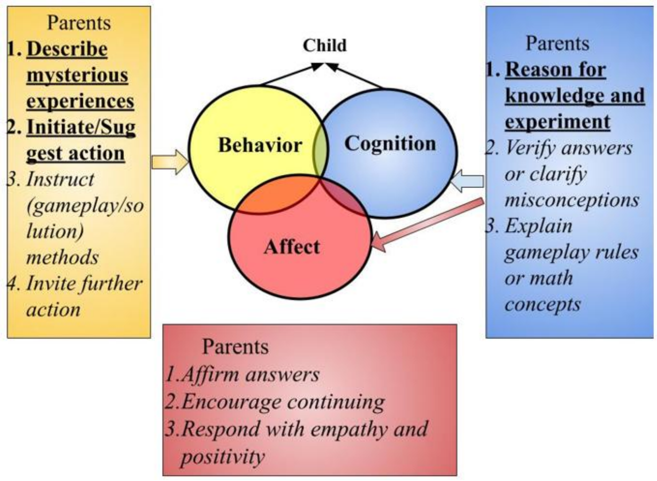

Figure 3. Refined model: Parental VP and child PRs in ABC (Source: Authors' own elaboration)

Refined Model: Parental VP and Child PR in Affect, Behavior, and Cognition

A synthesis of the findings regarding VPa, VPb, and VPc reveals distinct patterns in their predictive relationships with child PR. VPa and VPc demonstrated more complex or cross-domain predictive relationships with PRa and PRc, y

ively. In contrast, VPb exhibited a more pronounced, domain-specific relationship in predicting PRb. Furthermore, overall child PR (PRm) was significantly predicted by the aggregate measure of VPc (VPcm; model 7). Model 8 further indicated that VPc3 specifically predicted PRm, even when accounting for factors such as later stages of gameplay (associated with increased PR) and inter-pair differences (**Table 2**).

Integrating these varied findings allows for the construction of a model depicting the relationships among VPa, VPb, and VPc (**Figure 3**). A key premise underlying this model is that all VPs identified through qualitative methodology are not only theoretically meaningful but were also authentically employed by parents. Consequently, all specific VP strategies observed in this study are considered essential components and are therefore incorporated into the proposed framework.

Quantitative analyses further elucidate the relationships between parental VP and child PRs. Among these, VPc3 (parental reasoning for knowledge and experimentation) emerged as the most significant VP impacting overall PRs, predicting not only children's cognitive responses but also their affective responses. This finding aligns with research in formal educational settings demonstrating that conceptual, higher-order scaffolding enhances students' perseverance in mathematical problem-solving (DiNapoli & Miller, 2022). Subsequently, VPb4 (describing mysterious experiences) and VPb3 (initiating or suggesting particular actions) were identified as key behavioral VPs that specifically predicted child behavioral responses.

All the VPa fails to predict students' PRs in all the ABC aspects. This finding looks contrary to the prediction of the model (**Figure 1**) but may be explained by the ABC of social learning (Gruber et al., 2022), where affect is a basic, hidden, and bidirectional (with positive and negative) layer to transmit values (, compared with behavioral and cognitive aspects. Culture may also play a role when strict affectionate or tiger-mother parenting may play a positive role in Chinese culture (Ren et al., 2025). The pervasive, hidden layer of VPa may be pervasive and thus reduce its predictive capacity in all the regression models (**Figure 3**).

VPa did not emerge as a significant predictor of children's PRs across any of the ABC domains (PRa, PRb, or PRc). This finding appears contrary to the initial model's predictions (**Figure 1**). However, this lack of direct predictive power may be understood through several lenses. First, the ABC model of social learning (Gruber et al., 2022) posits that affect serves as a foundational, often implicit, and bidirectional (encompassing both positive and negative states) layer for value transmission, distinguishing it from the more overt behavioral and cognitive aspects. Second, cultural factors may play a role; for instance, parenting styles like 'tiger mothering,' prevalent in some Chinese cultural contexts, have been associated with positive child outcomes despite differing affective expressions (Ren et al., 2025). Consequently, the pervasive and often implicit nature of VPa might obscure its direct predictive power in regression models (**Table 2** and **Figure 3**).

Limitations and Future Research Directions

This study relies on coding schemes and human coders. Although multiple procedures have been employed to enhance the trustworthiness of the coding, future research may consider utilizing modern techniques to analyze multimodal data (e.g., facial expressions using machine learning, physiological data through medical examinations, and brain function using advanced neuroscientific equipment). This may increase scientific indicators for the ABC aspects.

This study's reliance on coding schemes and human coders presents certain limitations. While multiple procedures were employed to enhance coding trustworthiness, future research could benefit from integrating modern techniques for analyzing multimodal data. Such approaches might include machine learning for facial expression analysis, physiological data collection, and neuroscientific methods to assess brain function.

The study's sampling strategy, which resulted in a sample exclusively composed of mother-daughter pairs from a specific cultural context, may have influenced the identified themes. Furthermore, the use of snowball sampling, particularly if initial participants were primarily mothers, might have inadvertently skewed the sample towards reflecting societal norms where mothers often assume greater childcare responsibilities than fathers (French et al., 2024). Consequently, future large-scale studies are warranted to investigate whether the gender of parents and children influences the identified VP categories and their relationships with child responses. Such research should prioritize gender-balanced sampling designs to enhance the generalizability of findings.

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Data sharing statement: The data obtained by the parent-child interaction and interview (fully recorded) are confidential. The content can be easily used to identify the participants, so the original data will not be open to the public. The apps are shared on the first author's website (https://sites.google.com/view/mei-shiu-chiu/about).

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