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The Moderate Predictability Model Understanding Incidental Learning Across Infants, Mothers, Children, and Scientific Communities

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Abstract: Incidental learning happens in many parts of human life, but it is usually studied in separate fields. Research on infant speech perception, maternal adaptation in infant-directed speech, children's spelling learning, and even the spread of scientific ideas all describe change without direct instruction. However, these findings are rarely brought together under one general theory. This paper addresses that gap by reviewing four peer-reviewed studies published between 2006 and 2019: Kuhl et al. on infant phonetic discrimination, Smith and Trainor on maternal vocal adaptation to infant feedback, Gibbons on the rise of the Parallel Distributed Processing volumes, and Samara et al. on incidental learning of graphotactic regularities. Through thematic synthesis and cross-case comparison, three common features emerge: learning depends on structured but not fully fixed patterns, feedback works more strongly when it supports an existing tendency, and important learning can happen without full conscious awareness. From this comparison, the Moderate Predictability Model (MPM) is proposed. The model suggests that incidental learning is strongest when the environment is neither random nor completely predictable, when reinforcement strengthens an already available pathway, and when knowledge develops implicitly before it can be explained explicitly. Although the model remains theoretical and should be tested directly in future research, it offers a simple and useful framework for understanding incidental learning across development, social interaction, and scientific culture.

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I. INTRODUCTION

Incidental learning refers to learning that happens without direct instruction about the exact pattern being acquired. It can be seen in infants, children, adults, and even in larger social systems such as scientific communities. Although these examples seem very different, they share an important feature: learning takes place even when the learner is not explicitly told what to learn. This raises an important question. If incidental learning appears across so many different settings, are there common principles behind it?

Most research does not answer this question in a unified way. Developmental psychology often studies infant speech learning and early literacy separately. Research on parent-infant interaction focuses on feedback and social behavior. Historical studies of science examine how ideas gain influence over time. These fields usually remain separate, even when they may be describing related processes. As a result, there is still no broad framework that explains incidental learning across different domains.

This paper brings together four studies as a small comparative data set. The first study examined how American and Japanese infants changed in their ability to discriminate the English /ra-la/ contrast between 6–8 months and 10–12 months of age. The second investigated whether mothers changed their pitch in infant-directed speech when infant reactions appeared to reward higher or lower pitch. The third explored why the 1986 Parallel Distributed Processing volumes became landmark texts in cognitive science. The fourth tested whether children could learn graphotactic patterns incidentally while completing a task that did not directly involve spelling.

At first glance, these studies seem unrelated. One focuses on infant speech perception, another on maternal behavior, another on the history of science, and another on literacy learning. However, all four involve learning or adaptation from patterned experience without direct teaching of a rule. This similarity suggests that the studies may reflect a shared logic.

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Existing theories explain parts of this picture but not all of it. Statistical learning theory explains how learners become sensitive to regularities in the input. Models such as the Perceptual Assimilation Model explain speech perception across languages. Critical period theories explain developmental changes in language learning. These approaches are valuable, but they do not fully explain why some patterns are especially learnable, why feedback often works in one direction more than another, or why learning often appears before conscious explanation.

This paper argues that the four studies point toward a common framework. Across them, learning seems to depend on patterns that are regular but not completely fixed, feedback that supports existing tendencies more easily than it reverses them, and knowledge that develops implicitly before it becomes explicit. These recurring features form the basis of the Moderate Predictability Model (MPM).

The guiding research question is: What common principles govern incidental learning in diverse populations and contexts?

II. METHODS

- *Design*

This paper is a theoretical and integrative review. It does not present new empirical data. Instead, it develops a conceptual framework by comparing four previously published studies that all involve learning without explicit instruction.

- *Study Identification*

The studies were selected through a targeted search using terms such as incidental learning, implicit learning, infant speech perception, infant-directed speech feedback, graphotactic learning, statistical learning spelling, connectionism history, and scientific canonization. Searches were carried out in academic databases commonly used in psychology, education, and related fields, including Google Scholar, Scopus, and PsycINFO. The aim was not to conduct an exhaustive review, but to identify a focused set of studies that could support cross-case comparison.

- *Inclusion Criteria*

Studies were included if they met four criteria. First, they had to be peer-reviewed and published between 2006 and 2019. Second, they had to present original empirical or historical data. Third, they had to address learning, adaptation, or uptake without explicit instruction in the target structure. Fourth, they had to provide enough detail to allow careful comparison. Based on these criteria, four studies were selected: Kuhl et al. (2006), Smith and Trainor (2010), Gibbons (2018), and Samara et al. (2019).

- *Analytic Approach*

The analysis proceeded in two steps. First, each study was summarized in terms of participants or units of analysis, design, major findings, and the authors' original interpretation. Second, the studies were compared across themes. The comparison focused on three main questions: what kind of structure supported learning, how feedback operated, and whether the learning appeared explicit or implicit. These shared themes were then used to develop the Moderate Predictability Model.

III. RESULTS

A. *Study 1: Infant Speech Perception*

- Citation: Kuhl, P. K., Stevens, E., Hayashi, A., Deguchi, T., Kiritani, S., and Iverson, P. (2006).
- Participants and design: Kuhl et al. compared American and Japanese infants at 6–8 months and 10–12 months of age on their ability to discriminate the English /ra-la/ contrast. The method used was a conditioned head-turn task, in which infants heard repeated sounds and were trained to turn when the sound changed.
- Key finding: At 6–8 months, American and Japanese infants performed at roughly similar levels, around 65% correct. By 10–12 months, American infants improved to about 74% correct, while Japanese infants declined to about 60%. This showed improvement for a native contrast and decline for a nonnative contrast.
- Original interpretation: The authors argued that infants become more committed to the phonetic structure of their native language during the second half of the first year.
- Gap for a unified model: The study explains speech-specific developmental tuning, but it does not address whether similar selective learning principles apply across other domains.

B. *Study 2: Maternal Feedback and Infant-Directed Speech*

- Citation: Smith, N. A., and Trainor, L. J. (2010).
- Participants and design: Smith and Trainor studied 18 mother-infant dyads with 4-month-old infants. Mothers and infants were placed in separate rooms. Mothers believed their speech was affecting infant reactions shown on video, but the infant responses were actually controlled by the experimenter. In one condition, infants appeared happier when mothers used higher pitch. In the other condition, infants appeared happier when mothers used lower pitch.
- Key finding: Mothers increased pitch over time in the high-pitch reinforcement condition, from about 0.57 to 0.66 octaves above baseline. However, they did not similarly lower pitch in the low-pitch condition, remaining around 0.47 octaves. Feedback therefore worked in one direction but not the other.
- Original interpretation: The authors concluded that infant-directed speech is shaped by infant feedback, but that natural constraints influence which changes are more likely.

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- Gap for a unified model: The study shows contingent adaptation, but it does not explain more generally why reinforcement strengthens an existing tendency more easily than it reverses one.

C. Study 3: Scientific Canonization and the PDP Volumes

- Citation: Gibbons, M. (2018).
- Participants and design: Gibbons conducted a historical analysis of how Rumelhart and McClelland's 1986 Parallel Distributed Processing volumes became landmark texts. The study used reviews, citations, oral histories, publication records, and textual analysis.
- Key finding: Several factors contributed to the success of the PDP volumes: favorable timing, a relatively low price of about $45 rather than something closer to $150, strong promotion, early rapid uptake, and strategic ambiguity that allowed different audiences to interpret the books in ways that suited their own interests.
- Original interpretation: Gibbons argued that landmark status depended not only on theoretical merit but also on material, historical, and rhetorical conditions.
- Gap for a unified model: The study explains why a scientific work became influential, but it does not connect this process to broader principles of incidental learning and adaptation.

Study 4: Incidental Learning of Orthographic Regularities

- Citation: Samara, A., Singh, D., and Wonnacott, E. (2019).
- Participants and design: Samara et al. studied 78 English-speaking children with a mean age of 7.24 years and 37 Turkish-speaking children with a mean age of 6.73 years. Children viewed novel three-letter strings while doing a color-detection task. They were not told to learn spelling patterns. Across two sessions, they received 288 exposures to graphotactic constraints in either word-initial or word-final positions and later judged whether new strings were acceptable.
- Key finding: Both groups showed evidence of learning the graphotactic constraints. For example, English-speaking children in the word-initial condition judged legal items as acceptable more often than illegal items, 61% versus 53%. Bayes Factors supported learning overall, but evidence for a word-final advantage over a word-initial advantage was inconclusive.
- Original interpretation: The authors concluded that children can learn orthographic regularities through statistical exposure even when learning is not the stated task.
- Gap for a unified model: The study demonstrates incidental learning in literacy, but it does not explain why similar hidden structure may support learning across very different contexts.

IV. THEORETICAL FRAMEWORK: THE MODERATE PREDICTABILITY MODEL (MPM)

- *Overview of the Model*

The Moderate Predictability Model proposes that incidental learning across domains is guided by three connected principles: a moderate predictability optimum, asymmetric feedback gating, and unconscious representational encoding. The model is intended as a broad conceptual framework rather than a narrow mechanism for just one area.

In this model, predictability refers to the conditional probability that a target event occurs in a given context. Predictability is high when cues are highly reliable, low when they are mostly random, and moderate when there is structure but also some variation. MPM proposes that incidental learning is often strongest in this middle range.

- *Principle 1: Moderate Predictability Optimum*

Definition. Learning is maximized when the conditional probability of a target event given a context falls roughly between .60 and .80. In this range, there is enough regularity to notice a pattern, but enough variation to encourage abstraction and flexible representation.

This principle helps explain all four studies. In Kuhl et al. (2006), infants learned from speech input that was patterned but variable, not from perfectly identical sounds. In Smith and Trainor (2010), mothers responded to meaningful feedback that strengthened a familiar pattern rather than creating a reversed one. In Samara et al. (2019), children learned statistical spelling-like patterns that were hidden within another task, which made the structure regular but not fully explicit. In Gibbons (2018), the PDP volumes succeeded partly because they were interpretable across multiple audiences: they were structured enough to be taken seriously, but open enough to attract different fields.

The broader point is that learning may benefit most from environments that are neither too chaotic nor too rigid. Moderate predictability gives the learner something stable to detect, while still requiring mental processing beyond simple repetition.

- *Principle 2: Asymmetric Feedback Gating*

Definition. Reinforcement can strengthen a pre-existing behavioral bias, but it cannot easily reverse it in a short period unless that bias is already weak.

Smith and Trainor (2010) provide the clearest example. Mothers raised pitch when higher pitch seemed to produce positive infant feedback, but they did not lower pitch to the same extent when low pitch was rewarded. This suggests that feedback does not operate symmetrically. Instead, it works more strongly when it supports an already preferred direction.

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A related pattern appears in Kuhl et al. (2006). American infants improved on native contrasts, while Japanese infants declined on the English contrast. This is not just a simple case of one skill increasing while another decreases at the same rate. Rather, the learning process appears to favor commitment to patterns that fit the environment. Native facilitation is stronger than complete preservation of all contrasts.

The same idea can be extended to the other studies. In Samara et al. (2019), children learned the structure they were exposed to, but the results did not show that one form of positional learning could be forced into superiority under all conditions. In Gibbons (2018), the PDP volumes were successful because the field was already ready for connectionist ideas. Historical timing functioned like a form of feedback, but only because the intellectual environment was receptive.

This principle suggests that incidental learning is not unlimited flexibility. Systems adapt, but they do so along pathways that are already more available than others.

- *Principle 3: Unconscious Representational Encoding*

Definition. Incidental learning often produces implicit, non-declarative knowledge that shapes later judgments or behavior even when the learner cannot clearly explain the rule or source of change.

Samara et al. (2019) provide the clearest evidence for this. The children were not taught the graphotactic rules directly, yet their later judgments showed that learning had occurred. Their responses reflected acquired knowledge even without explicit rule awareness.

Smith and Trainor (2010) also support this principle. Mothers did not know that infant reactions were being controlled to reinforce certain pitch patterns, yet their behavior changed in the high-pitch condition. Likewise, Kuhl et al. (2006) describe infants developing perceptual sensitivities long before they could explain anything about speech categories.

Gibbons (2018) suggests a similar pattern at the social level. Scientific communities often describe landmark books mainly in terms of intellectual merit, but timing, pricing, and rhetorical openness also shape uptake. These influences may affect collective behavior even when they are not fully acknowledged.

Taken together, the evidence suggests that learning can change behavior before it becomes available for clear explanation.

V. COMPARISON TO EXISTING THEORIES

- *Statistical Learning Theory*

Statistical learning theory, especially as described by Saffran, Aslin, and Newport (1996), shows that learners can extract regularities from input without explicit instruction. MPM agrees with this tradition, but adds two further claims. First, it proposes that learning is strongest not simply under maximum regularity, but under moderate predictability. Second, it argues that feedback often works asymmetrically because it passes through existing biases.

- *Perceptual Assimilation Model*

Best's (1995) Perceptual Assimilation Model is highly useful for explaining cross-language speech perception. However, it is mainly focused on speech. MPM extends beyond phonetic learning to include maternal vocal behavior, children's orthographic learning, and the uptake of scientific texts. Its contribution lies in scope rather than in replacing speech-specific models.

- *Critical Period Hypothesis*

Critical period theories explain developmental changes in language learning through sensitive windows of plasticity. MPM does not reject this idea, but it places more emphasis on selective narrowing. From this perspective, decline in some sensitivities may reflect asymmetric learning and commitment to environmental structure rather than simple loss alone.

VI. DISCUSSION

The four studies reviewed here differ widely in topic and method, yet they share several important features. One examines infant speech perception, one maternal vocal adaptation, one the historical success of a scientific framework, and one incidental literacy learning in children. Despite these differences, all four involve adaptation to structured experience without direct teaching. This is the main reason they can be meaningfully compared.

The Moderate Predictability Model explains the studies through three central ideas. First, learning seems to benefit from structure that is present but not complete. In infant speech perception, the environment provides repeated regularities without perfect sameness. In incidental spelling learning, children detect patterns that are hidden within another task. In the history of science, ideas may spread more effectively when they are clear enough to guide interpretation but open enough to attract different audiences. In each case, there is enough structure to support learning, but not so much that interpretation becomes unnecessary.

Second, feedback appears to work directionally rather than symmetrically. This is most obvious in the study by Smith and Trainor, where mothers increased pitch under reinforcement but did not lower it in the opposite condition. A similar logic can be seen in infant phonetic learning, where development strengthens native sensitivity more strongly than it preserves universal sensitivity. The same principle may also help explain why scientific communities adopt ideas most easily when those ideas fit an already favorable context.

Third, the reviewed studies show that important learning can happen without explicit awareness. Infants cannot explain phonetic learning. Children in incidental spelling

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tasks often cannot verbalize the rules they have acquired. Mothers in the feedback study were unaware of the manipulation. Even scholars may not fully recognize the role that timing, pricing, and interpretive openness play in shaping intellectual influence. This suggests that conscious explanation is often a later outcome rather than the starting point of learning.

At the same time, the model has important limitations. Only four focal studies were included, which is enough for theory-building but not for establishing a universal law. In addition, the proposed predictability range of .60 to .80 is a hypothesis derived from synthesis, not a directly tested conclusion from the reviewed studies. Other factors such as attention, motivation, salience, and emotion may also shape the outcomes. The model should therefore be treated as a theoretical proposal rather than a final answer.

Future studies could test MPM more directly by manipulating contingency strength across a range from .50 to 1.00 and measuring learning outcomes. Similar experiments could test whether learning truly peaks in a moderate range rather than rising steadily with stronger regularity. Research could also examine how explicit awareness emerges from implicit learning over time. Such studies would help evaluate whether MPM is only a useful metaphor or a genuinely predictive framework.

If supported, the model could have practical implications. Education may benefit from repeated, meaningful exposure to structured material rather than relying only on direct rule explanation. Early childhood interaction may matter partly because it provides rich but manageable patterns. Scientific communication may also benefit when ideas are presented clearly but with enough openness to connect with multiple audiences. More broadly, the model suggests that learning works best when environments combine reliability with flexibility.

VII. CONCLUSION

This paper asked a broad question: what common principles govern incidental learning in diverse populations and contexts? By comparing four studies from infant speech perception, maternal feedback, scientific canonization, and orthographic learning, it proposed the Moderate Predictability Model as a unified framework. The model argues that incidental learning is strongest when patterns are moderately predictable, when feedback strengthens existing biases more easily than it reverses them, and when knowledge develops implicitly before it can be explicitly explained.

Taken together, these principles offer a simple and coherent account of incidental learning across development, social interaction, and scientific reception. Although the model remains theoretical, it provides a useful way to connect findings that are often studied separately. In that sense, the Moderate Predictability Model offers a promising starting point for future research on how learning emerges from patterned experience without direct instruction.

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- *Data Availability*
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