Theoretical Foundations of the VHS Kids Profession Simulation: A Principled Selection of Formal Frameworks

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Abstract

This paper provides a formal account of the theoretical framework underlying VHS Kids, a profession simulation module for children aged 10–14 embedded in the SWARP platform. The framework integrates five components: Schank's Case-Based Reasoning (CBR), McWhinney's four-worldview model formalised as quaternion operators, Holland's RIASEC taxonomy linked to the O*NET occupational database, Friston's Free Energy Principle (FEP), and Human Design as a prior signal. Each component is shown to be a necessary response to a specific formal requirement left unresolved by the preceding components. The central claim is that the convergence is structurally constrained, not eclectic: no component is replaceable without undermining the formal integrity of the whole. The paper further demonstrates that the O*NET–RIASEC–McWhinney linkage constitutes a reverse-engineering of existing empirical occupational data into the quaternion operator space, via a fixed projection matrix **M**, enabling cosine-similarity matching between individual cognitive profiles and occupational failure patterns at scale.

Keywords: case-based reasoning, quaternion operators, RIASEC, O*NET, free energy principle, occupational simulation, expectation failure

1. Introduction

Career orientation instruments for children are predominantly taxonomic: they present ranked lists of occupations derived from self-reported preference scores. Such instruments produce exposure, not learning. The child has not experienced work; they have read a description of it. This design deficit follows directly from the absence of a failure mechanism. Learning, in the cognitive-scientific literature, requires not information transfer but the structured violation of expectation (Schank & Abelson, 1977; Schank, 1982). A simulation that does not engineer failure is a test of existing competence, not a generator of new competence.

The design of VHS Kids begins from this requirement: the system must produce specific, classifiable, recoverable expectation failures calibrated to the cognitive profile of the individual child. Meeting this requirement imposes a cascade of formal constraints, each demanding a specific theoretical instrument. Section 2 through Section 6 of this paper address each constraint in turn.

2. Case-Based Reasoning as the Learning Architecture

2.1 Selection Rationale

The foundational requirement is a computable learning mechanism — one that specifies not merely what learning is, but how to engineer it. Schank's Case-Based Reasoning (CBR) satisfies this requirement. CBR formalises memory as an indexed structure of cases (scripts), not a rule base. Learning is defined as index revision triggered by the mismatch between a retrieved case and an observed outcome — the *expectation failure* (Schank, 1982; Schank & Abelson, 1977).

Alternative frameworks considered — Bloom's taxonomy (1956), Piaget's constructivism, Kolb's experiential learning cycle (1984) — are descriptive classifications of cognitive operations or learning conditions. None specifies, at an implementable level of abstraction, how to compile a learning event. CBR is the exception: the script is a data structure, the failure is a detectable event, and the revision is a computable update. This is why CBR is selected as the learning architecture.

2.2 CBR as a Discrete Approximation of Bayesian Updating

The relationship between CBR and the Free Energy Principle (§6) is not merely analogical but formally derivable. A CBR case is a point mass in state space; a FEP generative model is a distribution over states. The mapping is as follows:

- Case retrieval → prior $p(s)$ selection
- Professional expectation → likelihood $p(o|s)$
- Expectation failure → prediction error: deviation of observed o from predicted o
- Case update → posterior update: $q\_new(s) \propto p(o|s) \cdot q\_old(s)$

CBR is therefore a sparse, discrete approximation of Bayesian updating under the Free Energy Principle. This formalisation strengthens the theoretical claim: the system does not rest on two independent learning theories but on one underlying principle (free energy minimisation) instantiated at two levels of abstraction — continuous probabilistic (FEP) and discrete case-indexed (CBR). Section 6 develops the FEP treatment; the present section establishes CBR as its computationally tractable approximation.

2.3 Implication for System Design

The CBR architecture implies that VHS Kids must maintain, for each of its 1,016 occupations, a structured case database specifying: (i) the professional expectation operative in a given scenario, (ii) the conditions under which that expectation fails, and (iii) the revised script that correct failure processing should produce. The construction of this database is addressed in Section 5.

3. McWhinney's Four Realities as a Failure Taxonomy

3.1 The Classification Requirement

CBR requires that expectation failures be classifiable. A feedback engine operating across 1,016 occupations cannot generate targeted corrective feedback without a domain-agnostic taxonomy of failure types. The required taxonomy must satisfy three conditions: completeness (every professional failure falls within one class), mutual exclusivity (classes do not overlap), and domain independence (applicable across all occupations without modification).

3.2 McWhinney's Framework

McWhinney (1997) identifies four irreducible cognitive modes — Unitary, Sensory, Social, Mythic — as the fundamental orientations from which all professional cognition and its characteristic failures derive. These four modes are not empirically induced categories but are structurally derived as the four combinations of two orthogonal dimensions (interior/exterior orientation × subjective/objective processing). This derivation guarantees completeness and mutual exclusivity by construction.

Each mode generates a characteristic failure type when applied in an incongruent context:

Mode	Failure Type	Description
Unitary	Integration failure	Systemic coherence imposed where negotiation is required
Sensory	Observation failure	Assumption treated as verified empirical fact
Social	Abstraction failure	Incorrect conceptual schema applied to situation
Mythic	Application failure	Correct model deployed in wrong context

This taxonomy satisfies all three requirements and is selected as the failure classification system.

4. Quaternion Algebra as Operationalisation

4.1 The Formalisation Requirement

McWhinney's four modes, while theoretically principled, remain conceptual. The third design requirement — calibration of failure difficulty to the individual child's cognitive profile — demands a computational representation of the four modes as operators over a common algebraic structure.

4.2 Structural Isomorphism with Quaternion Algebra

Hamilton's quaternion algebra (1843) provides a four-dimensional associative algebra over the reals with basis elements **{1, i, j, k}** satisfying $\mathbf{i}^2 = \mathbf{j}^2 = \mathbf{k}^2 = \mathbf{ijk} = -1$. The mapping to McWhinney's four modes is structurally constrained:

McWhinney Mode	Quaternion Basis	Cognitive Operation	Failure Type
Unitary	**1** (scalar)	Systemic integration	Integration failure
Sensory	**i**	Evidence gathering, perception	Observation failure
Social	**j**	Model construction, framing	Abstraction failure
Mythic	**k**	Contextual application	Application failure

The four operators are defined explicitly as functions on a situational state x:

- **i**(x) = observe(x): update internal model from sensory input
- **j**(x) = model(x): construct or select a generative schema
- **k**(x) = act(x): select action given current model
- **1**(x) = integrate(x): maintain coherence across model levels

Non-commutativity follows directly from the functional definitions: $\mathbf{j}(\mathbf{i}(x)) \neq \mathbf{i}(\mathbf{j}(x))$. A professional who observes first and then models reaches a different state than one who models first and then observes. This is order-dependence of information processing — an empirical property of professional cognition, not a mathematical stipulation. Quaternion algebra is the minimal algebraic structure that captures this path-dependence for four operators in three dimensions; no commutative alternative preserves it.

The individual's cognitive profile is represented as a unit quaternion:

$$\mathbf{q}\_PoC = w\_U \cdot \mathbf{1} + w\_S \cdot \mathbf{i} + w\_So \cdot \mathbf{j} + w\_M \cdot \mathbf{k}, \quad |\mathbf{q}\_PoC| = 1$$

where the component weights encode the relative frequency with which each operator is exercised. The dominant component identifies the primary failure mode; the under-represented components identify calibration targets for the simulation.

5. O*NET and RIASEC: Reverse Engineering of the Case Database

5.1 The Data Requirement

The quaternion operator framework provides the formal structure for failure classification. The system additionally requires empirical content: for each of the 1,016 occupations, concrete failure patterns must be specified. Manual construction of this database at the required scale is not feasible. The design requirement is therefore a principled method for deriving structured failure content from existing empirical occupational data.

5.2 O*NET as the Empirical Source

The O*NET database (Peterson et al., 2001; O*NET OnLine, 2024) provides standardised, empirically grounded descriptions of tasks, knowledge domains, skills, and work contexts for over 1,000 occupations. Crucially, O*NET encodes implicitly where professionals in each occupation characteristically fail: cognitively demanding tasks, frequent skill gaps, and context-specific misjudgement patterns are documented at the occupational level. The failure content is present in the data; it requires extraction, not construction.

5.3 RIASEC as the Bridge to the Quaternion Space

Each O*NET occupation is coded with a RIASEC profile (Holland, 1997) — a six-dimensional vector of occupational interest scores across the dimensions Realistic (R), Investigative (I), Artistic (A), Social (S), Enterprising (E), and Conventional (C). Holland's framework provides an empirically validated mapping between occupational cognitive demands and the same underlying cognitive dimensions that McWhinney's four modes describe from a theoretical perspective.

The projection from the quaternion PoC space to the RIASEC space is formalised as a linear map:

$$\mathbf{v}\_RIASEC = \mathbf{M} \cdot [w\_U, w\_S, w\_So, w\_M]^T$$

where $\mathbf{M} \in \mathbb{R}^{(6\times4)}$ is the fixed projection matrix encoding the correspondence between the four quaternion components and the six RIASEC dimensions. The matrix is derived from the structural correspondences between McWhinney's four worldviews and Holland's six occupational orientations (Konstapel, 2007; Holland, 1997):

$$\mathbf{M} = \begin{pmatrix} 0.0 & 0.7 & 0.0 & 0.3 \\ 0.0 & 0.3 & 0.0 & 0.7 \\ 0.0 & 0.0 & 0.3 & 0.0 \\ 0.0 & 0.0 & 0.7 & 0.0 \\ 0.3 & 0.0 & 0.0 & 0.0 \\ 0.7 & 0.0 & 0.0 & 0.0 \end{pmatrix} \quad \text{rows: R, I, A, S, E, C; columns: } w_U, w_S, w_{So}, w_M$$

The non-zero entries encode the following principled correspondences: Sensory (**i**) maps primarily to Realistic (R: concrete, physical, empirical engagement) with secondary loading on Investigative (I); Mythic (**k**) maps primarily to Investigative (I: analytical, abstract pattern recognition) with secondary loading on Realistic (R); Social (**j**) maps primarily to Social (S: relational, interpersonal engagement) with secondary loading on Artistic (A: expressive, contextual); Unitary (**1**) maps primarily to Conventional (C: rule-governed, systematic) with secondary loading on Enterprising (E: directive, goal-setting). Artistic (A) receives secondary loading from Social (**j**) reflecting the overlap between expressive and relational cognition in Holland's framework.

The column weights sum to 1.0 per quaternion component, preserving the unit-quaternion normalisation under projection. The resulting RIASEC vector is matched against O*NET occupational profiles via cosine similarity:

$$\text{sim}(\mathbf{v}_{\text{RIASEC}}, \mathbf{v}_{\text{occ}}) = \frac{\mathbf{v}_{\text{RIASEC}} \cdot \mathbf{v}_{\text{occ}}}{\|\mathbf{v}_{\text{RIASEC}}\| \, \|\mathbf{v}_{\text{occ}}\|}$$

This yields a ranked list of occupations ordered by cognitive-demand alignment with the child's operator profile. The case database is thus not constructed but reverse-engineered from empirically established occupational data through a formally defined linear projection from quaternion operator space into the RIASEC occupational space. The matrix **M** constitutes the only element of the framework not yet derived from first principles. Its entries are currently principled estimates based on structural correspondences; empirical calibration is required. The correct estimation procedure is:

$$\mathbf{M}^* = \arg\min_{\mathbf{M}} \sum_i \| \mathbf{M}\mathbf{q}_i - \mathbf{v}_i^{\text{RIASEC}} \|^2$$

where the sum runs over all 1,016 O*NET occupations, $\mathbf{q}_i$ is the quaternion operator profile assigned to occupation i from its O*NET work-context data, and $\mathbf{v}_i^{\text{RIASEC}}$ is the empirically measured RIASEC vector for that occupation. This is a standard least-squares regression problem; it is computationally tractable given the existing O*NET dataset and does not require additional data collection. Empirical validation of **M*** via correlation of predicted RIASEC profiles with measured occupational performance outcomes is identified as the primary target for subsequent work.

6. Friston's Free Energy Principle as a Formal Learning Norm

6.1 The Optimality Requirement

CBR specifies the mechanism of learning; it does not specify a norm for when learning is optimal. A system calibrating failure difficulty across sessions and children requires a formal criterion for optimality of model update.

6.2 FEP as the Norm

Friston's Free Energy Principle (2010) provides this criterion. The FEP states that any self-organising system maintains itself by minimising the divergence between its generative model and its sensory input — equivalently, by minimising variational free energy **F**:

$\mathbf{F} = E\_q[\log q(s) - \log p(o, s)]$

where q(s) is the approximate posterior over hidden states s and p(o, s) is the generative model. Learning corresponds to model update that reduces **F** in response to prediction error.

This is formally equivalent to Schank's expectation failure mechanism: the prediction error in FEP corresponds directly to the expectation failure in CBR. The four quaternion operators correspond to the four operations of an active inference agent: **i** (perceptual update — posterior revision given sensory input), **j** (model selection — generative model construction), **k** (active inference — action selection to produce predicted input), **1** (hierarchical integration — coherence maintenance across model levels).

FEP provides two contributions not available from CBR alone: (i) a formal optimality criterion for failure difficulty calibration (failures should maximise expected information gain, i.e., expected reduction in **F**), and (ii) a principled connection to the empirical neuroscience of learning and plasticity.

7. Human Design as a Physical Prior

7.1 The Derivation Chain: Maxwell → Interpersonal Theory → McWhinney → Human Design

The theoretical status of Human Design in this framework is not that of an unvalidated typological system but of a pre-scientific measurement instrument for an electromagnetic field topology that is physically grounded in Maxwell's field equations.

The derivation chain rests on a structural observation made by the present author (Konstapel, 2007): Sullivan's Interpersonal Theory, formalised by Horowitz (2004) as the Interpersonal Circumplex, is structurally isomorphic with Maxwell's dynamical theory of the electromagnetic field (1865). Maxwell describes field propagation along two orthogonal dimensions — the magnetic vector potential (agency, compression) and the electric displacement field (communion, expansion). The Interpersonal Circumplex is independently defined by precisely the same two orthogonal axes: agency and communion. This isomorphism was not stated by Sullivan and is not claimed in the Interpersonal Theory literature; it is an observation of formal structural identity between two independently developed frameworks.

The four quadrants generated by the agency/communion axes of the Interpersonal Circumplex map isomorphically onto McWhinney's four worldviews: the same two-dimensional orthogonal structure produces the same fourfold partition. McWhinney's framework can therefore be read as a third independent rediscovery of the same underlying structure. Human Design, in this reading, is a fourth: a pre-scientific instrument for measuring the individual's characteristic position within this same four-quadrant field topology.

Human Design, in this reading, is a pre-scientific instrument for measuring the individual's characteristic electromagnetic field topology — the stable rotation class of their bio-electric field at birth. The five HD Types are rotation classes of this field; the profile derived from birth data is a measurement of which rotation class characterises the individual's field organisation. Since the quaternion operators are the formal representation of the same four-quadrant EM structure, the HD profile is not a prior in the Bayesian sense of an uninformed initialisation but a physical measurement of the individual's position in quaternion operator space.

7.2 Implication for System Architecture

This grounding changes the epistemological status of the HD-derived operator weights from defeasible prior to physically motivated initialisation. The cold-start operator profile is not an assumption to be overridden by session data but a measurement to be refined by it — precisely as any physical measurement is refined by subsequent observation. The system architecture remains identical; the interpretation of the initialisation changes from heuristic to empirical.

8. Discussion

The five components described in Sections 2–7 form a closed dependency chain. CBR requires a failure taxonomy (§3); the taxonomy requires algebraic operationalisation (§4); the operationalisation requires empirical content (§5); the content requires a formal learning norm (§6); the norm requires a prior for cold-start conditions (§7). Each component is necessary; no component is sufficient without the others.

The O*NET–RIASEC–McWhinney linkage (§5) constitutes the methodological core of the framework. It demonstrates that the theoretical structure (quaternion operator space) and the empirical content (O*NET occupational database) are connected not by assumption but by a formally defined linear projection. The projection matrix **M** is the only element of the framework not yet derived from first principles; its specification from the theoretical correspondence between McWhinney's modes and Holland's RIASEC dimensions is identified as the primary formal task for subsequent methodological work.

9. Conclusion

This paper has demonstrated that the theoretical framework of VHS Kids is structurally constrained. Each of its five components is a formally necessary response to a requirement left open by the preceding components. The convergence is not eclectic assembly but a deductively closed chain from a single design requirement — engineered, classifiable, calibrated expectation failure — to a fully specified system architecture. The primary open problem is the formal derivation of the projection matrix **M**; all other theoretical junctions have been closed.

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