The free energy principle and its implications to language learning and education: 4E cognition, prediction, accuracy-complexity trade-off, intrinsic motivation via epistemic emotions, 4 skills

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Introduction

Closely related to applied linguistics (AL) and second language acquisition (SLA), foreign language learning and education (FLLE) is an interdisciplinary field where various theories and insights from varied academic domains have been applied, bridging theories with practices. Cognitive science is one such domain, from which FLLE studies have imported theories and insights such as consciousness (Truscott, 2015), working memory (Baddeley, 2015), and processing load allocation (Barcroft, 2015) as well as psycholinguistic experimental methodologies. One noteworthy theoretical framework in the state-of-the-art cognitive neuroscience and biophysics is the free energy principle (FEP; recently also known as Active Inference). It was introduced by Professor Karl J. Friston in the mid-2000s (Friston et al., 2006) and has been elaboratively and cross-disciplinarily developed ever since, making it a promising groundbreaking unifying theory of the brain, or further, the dynamics of living systems (Ramstead et al., 2018).

Although the FEP has provided powerful scientific research programs applicable to linguistic communication (Friston et al., 2020), its implications have not been well considered in the field of FLLE except for few emerging neuroscientific attempts such as Kajiura et al.'s (2021) brilliant fMRI study. The insufficient adaptation so far would be partly due to the intricate and profound mathematical formulations and the highly

specialized scientific apparatus of the FEP study that are often not affordable for FLLE researchers and pedagogical practitioners. Rigorous mathematical formalization and neurocomputing simulations, however, are not the exclusive approach of the FEP as it could also be applied to interdisciplinary investigations including philosophical approaches (Hohwy, 2013; Nave et al., 2020; Sims & Pezzulo, 2021; Mann et al., 2022). In this paper, the author introduces some key concepts of the FEP framework (Parr et al., 2022) in a greatly simplified manner and argues what language learning researchers and educational practitioners can learn from them.

1. Embodied, embedded, enacted, and extended — 4E cognition

To start with, the significant view in the latest cognitive science (viz., the 4E cognition) is briefly reviewed while explaining how it is relevant to FLLE and harmonious with the FEP. The traditional Cartesian dichotomous view to regard rational cognition as an archenemy of bodily emotion is less and less supported by the latest scientific findings (Kanazawa, 2019b). Moreover, it has been revealed that cognition (such as thinking, reasoning, and learning) cannot be explained solely as the computation of representational mental structures in the brain (Newen et al., 2018). In fact, extracranial bodily processes and brain-body interaction play important roles in cognition (i.e., embodied cognition). In addition, cognition does not function in vacuo but is situated in contexts (i.e., embedded cognition). Furthermore, cognition is action-oriented and autopoietic, engaging in the environment as well as actively affecting it (i.e., enacted cognition). Moreover, objects outside the head — and even the body — may play important roles in cognitive processes, and thus they can be integrated into cognition (i.e., extended cognition). In other words, the conventional computer metaphor of the brain and cognition is no longer valid because mind, body, emotion, and environment are organically intertwined with each other and integrated into cognition. Thus, when studying cognitive processes, the embodied, embedded, enacted, and extended aspects and nature of cognition ought to be well reminded (4E cognition).

Since language learning is a type of cognitive process, 4E cognition is relevant to FLLE. As for the embodied cognition, physical and bodily practices have been incorporated into pedagogy, such as total physical response and shadowing (Asher, 1969; Kadota, 2019). As for the embedded cognition, the fundamentality of social interaction and learning contexts have been proposed and modeled (The Douglas Fir Group, 2016; Collentine & Freed, 2004).

As for the enacted cognition, recent educational approaches such as task-based language teaching and project-based learning are oriented toward the enactive approach (Ellis et al., 2019; Thomas, 2017). As for the extended cognition, ICT instruments and generative AI tools have opened new frontiers in education (Su & Yang, 2023). Furthermore, affordance — an ecological psychology concept closely related to the 4E cognition paradigm — has been applied to language learning (van Lier, 2004).

Whereas traditional information-processing models of learning and processing often fail in organically incorporating the 4E aspects, such criticism does not apply for the FEP framework. In the FEP terms, although internal states (brain — generative models) and external states (world — generative processes) are theoretically divided because it is a prerequisite for a living thing to maintain its individuality without merging into the environment, between the two states are the Markov blanket states, which mediate interactions between the internal system and the external environment in a bidirectional manner (Figure 1; cf. Parr & Pezzulo, 2021). The implicit generative models are used and adjusted by the brain to explain the observed data presented by the environment via sensory states (i.e., embeddedness). Notably, the sensory modality is not always exteroceptive; it can also be proprioceptive or interoceptive (i.e., embodiedness). What is more, the implicit generative models also represent beliefs about how the external generative process should be, affecting the environment by performing actions via active states (i.e., enactedness). Further, the Markov blanket can be flexibly defined in nested manners, enabling even incorporating objects external to the body into the adaptive system (i.e., extendedness). In sum, the FEP framework provides a cohesive and comprehensive picture of the dynamically interacting 4E cognition, which is also relevant and potentially applicable to FLLE.

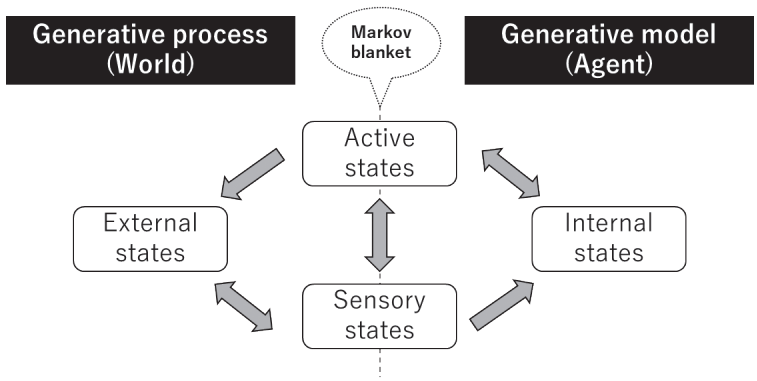

Figure 1. Action-perception loop in the free energy principle (drawn by the author based on Parr et al., 2022, p.108)

2. Omnipresent prediction — perception as unconscious inference, prediction-based learning

Perception, which underlies input processing such as reading and listening, is often conceptualized as an intrinsically uni-directional bottom-up process. In the context of FLLE, it is proposed that learners should make conscious efforts to employ top-down reading comprehension strategies, such as guessing and evaluating, to be a skilled reader (Abraham, 2000). The hidden premise here is that reading essentially concerns input-based data-driven decoding, and that additional attention of consciously making predictions and inferences will turn its passive nature toward more active and top-down processing. In most theories on reading including the recent interactive processing approaches, bottom-up processing is the basic mode of reading on which top-down concept-driven perspectives and strategies can be added pro re nata, and not vice versa (Grabe & Stoller, 2020).

The dominant view above, however, is not always supported by the latest cognitive scientific findings — especially concerning the fundamentality of predictions. As a demonstration, try reading the next sentence. Msot raeders wlil be albe to udnersntad waht is wreittn in tihs setnecne wtih julbmed letrtes. This shows that your brain automatically predicts what the words should be without decoding words letter by letter in a bottom-up manner. Another example in experimental psychology is a phenomenon called masked priming, in which a prime visually presented for a very short time (such as 50 milliseconds) can affect the processing of the subsequently presented target stimulus without the mediation of consciousness. Interestingly, although the duration of the prime

presentation is too short for a participant to be consciously aware of it, the priming effect can be observed even at the semantic levels (de Wit & Kinoshita, 2015). This exemplifies unconscious predictions our brain is constantly making, triggered even before the target stimulus is presented. Further examples and lucid explanations on the power of predictions can be found in excellent academic and popular science books (Hohwy, 2013; Barrett, 2021).

Based on the Helmholtzian idea of perception as unconscious inference and the Bayesian brain hypothesis, the FEP proposes that perception is an inferential process that always combines top-down prior information with bottom-up sensory stimuli. Notably, such inferencing functions below the threshold of consciousness. In other words, our brain is constantly making predictions even when we are not consciously aware of it. Such inferential processes follow Bayes' rule, updating the generative models (i.e., probabilistic representations of how external states generate sensory sensations). As Parr et al. (2022) eloquently conclude, "[p]erception is not a passive outside-in process—in which information is extracted from impressions on our sensory epithelia from "out there." It is a constructive inside-out process—in which sensations are used to confirm or disconfirm hypotheses about how they were generated" (Parr et al., 2022, pp.15–16). Such an active nature of perception is manifested by its multitude of epistemic actions including eye movements and tactile operations (Schwarzfischer, 2021). Needless to mention the profound rationality of perception (Krishnamurti & Bohm, 1980/1985), input processing is now proven to be an active and social process that entails unconscious automatic predictions and emphatic synchronization that start functioning even before the stimulus is presented.

Although the fundamentality of prediction in cognitive processes has recently been recognized and applied to studies in language comprehension (Ryskin & Nieuwland, 2023) and second language processing (Bovolenta & Marsden, 2022), the perception-as-inference view has not been widely recognized by FLLE researchers and teachers with a few emerging exceptions (Ikari et al., 2022; Kadota, 2023). Future FLLE theories and practices may well recognize the active nature of perception and try to operationalize it, such as via applying the prediction-based learning insights (MacRae et al., 2021). The FEP framework will provide a solid theoretical foundation on which the rationales of different language learning tasks and educational activities could be situated.

3. Free energy minimization — quintessential inseparability of perception and action, trade-off between accuracy and complexity, CAF

The FEP is not the only model that theorizes the predictive nature of perception. What makes it outstanding is its extension from perceptional inference to active inference, and the resulting unifying theory of perception and action under the same underlying mechanism of free energy minimization. The FEP posits that minimizing surprise is the imperative of living organisms to maintain themselves in their interaction with the environment while avoiding global thermodynamic equilibrium. In other words, the discrepancy between the agent's current sensory states reflecting the external states and the generative models that predict the preferred states should be minimized (Parr et al., 2022). The bigger the discrepancy is, the bigger the surprise will be (e.g., what you had assumed to be true turned out to be wrong). Minimizing surprise itself, however, is a challenging problem because the organism cannot directly evaluate the computationally intractable quantity, and thus organisms would have to do the impossible work to make inferences over all the possible states it could sample (Kiverstein & Sims, 2021). Organisms, however, can take a detour by indirectly minimizing the proxy, i.e., free energy, which is an upper bound on surprise value given a generative model (Friston, 2009). Because free energy is a function of the organism's internal dynamics and its sensory and active states, regulating its internal states and the states of its perception and action systems will enable an organism to decrease free energy, resulting in minimizing surprise (Kiverstein & Sims, 2021). There are two ways of regulation: changing the internal states in response to external perturbations (perception — changing yourself); or, changing the active states and thus selectively changing the aspect of external states you interact with, resulting in receiving the preferred sensory states (action — changing the world).

As an analogous example, imagine you are visiting a remote foreign country where you expect no local people to be able to speak your mother tongue. One day, surprisingly enough, you hear someone speaking in your mother tongue when you are walking in a crowd. You could either update your belief and accept the fact that your mother tongue is spoken there as well (perception — changing yourself). Alternatively, you could also take action by walking closer to the person so that you could listen more clearly. You could talk to her further to make sure she surely was speaking in your mother tongue. It may turn out that you just misheard a local dialect as your mother tongue, such as via coincidental interlingual homophones (action — changing the world). Both of these processes can be

explained by the same principle of minimizing surprise (internal-external discrepancy) via minimizing free energy. Perception and action are not two separate systems with different mechanisms but are two emergences of the same mechanism. Together with the mediation of emotional feelings, perception and action are inextricably fused (Eder, 2023).

Mathematically, free energy can also be formulated and defined as the difference between complexity and accuracy, where the goal of inference is minimizing complexity while maximizing accuracy (Mann et al., 2022). Here, complexity is the difference between the recognition density and the prior density (i.e., Bayesian surprise) whereas accuracy is the surprise about sensations that are expected under the recognition density (Friston, 2010). Simply put, the best generative models are the simple and accurate ones. Accuracy can be improved by action control, but that could also entail increased complexity. After all, the simplest models may lack important informational details and thus they may end up being useless. As Parr et al. (2022) quote Albert Einstein, "everything should be made simple as possible, but not simpler" (p.63). To give an example, although the Copernican heliocentric universe is simpler than the Ptolemaic geocentric system that calculates the eccentricity of the equant point, the new cosmology is still loaded with sets of sophisticated mathematical apparatus and concepts to ensure its accuracy. The FEP is a framework that theorizes the trade-off and the balance of accuracy and complexity.

What can FLLE learn from these facts? At least two speculative implications could be derived. First, similarly to the relation between perception and action in the FEP, input processing (viz., reading, listening) and output production (viz., writing, speaking) may also be inseparable and explained via the same underlying mechanism. The inseparability will also pave the way for the organic mixture, giving a potential rationale for multimodal communicative interaction. Second, the trade-off of accuracy and complexity may well deserve more recognition. One flourishing attempt of unifying explanation and measurement of second language performance is to suppose three constructs as basic dimensions: complexity, accuracy, and fluency (CAF; Housen et al., 2012). Popularized understanding of CAF may lead teachers to assume they should foster all these three dimensions in their students' second language performances. This guiding light, however, may result in cognitive overload when adopted at once. Free energy as complexity minus accuracy — plus fluency that underwrites the precision in the FEP (Brouillet & Friston, 2023) — may provide a comprehensive CAF account of realistic language proficiency development.

4. Into the temporal depth — expected free energy, intrinsic motivation toward exploration, emotional valence, epistemic emotions

We have seen in the previous section that different cognitive functions could be explained via the common principle of minimizing surprise. Readers may wonder that minimizing surprise could end up in stubbornly persisting to its own econiche via homeostasis and allostasis. Such a strategy may be maladaptive in the long run because it essentially disfavors newness, trying to keep itself within the comfort zone, unable to cope with unpredictably challenging situations in the future. Indeed, needless to quote Socrates, wisdom begins in wonder in the face of the unexpected, and wonder is an epistemic surprise. In actuality, the free energy discussed in the previous section measures the fit between the internal generative model and observations only at present and in the past, lacking in temporal depth. Although this may suffice for evolutionarily lower organisms in the phylogenetic tree that exist only in the here-and-now concerns, it is too temporally shallow for human beings to exercise their higher cognition and deliberate future planning capabilities.

Here, generative models endowed with temporal depth and hierarchical temporal structures are called for, resulting in extending the scope of the FEP from the original free energy (variational free energy) to the expected free energy (Schwartenbeck et al., 2013; Friston, Rosch et al., 2017). Expected free energy computations depend not only on prior preferences but also on prospective future observations of the posterior beliefs and the expected information gains of different potential policies. Minimizing expected free energy is accomplished in one of two ways (Friston et al., 2015): maximizing utility based on prior preferences (pragmatic value) or maximizing information gain by reducing uncertainty about the causes of valuable outcomes (epistemic value). The former is the case in which the predicted outcomes are consistently expected, resulting in exploitative decision-making. On the other hand, the latter intrinsically motivates explorative decision-making such as novelty-seeking and information-foraging behaviors that will help minimize the ambiguity of future beliefs via uncertainty resolution (Parr et al., 2022). The pragmatic/exploitative imperative and the epistemic/explorative imperative should not be regarded as ontological dichotomies. Instead, they are "just two sides of the same existential coin" (Parr et al., 2022, p.37) — just as perception and action are.

What is notable in expected free energy regulation is that the automatic balancing of exploitative policy selection and explorative policy selection is partly mediated and

motivated by emotional feelings (Demekas et al., 2020). From the first place, the concept of free energy itself is inseparable from the notion of surprisal — the informational *surprise*. In addition, consistently successful predictions of the world (pragmatic exploitation) will result in decreased marginal utility, triggering the feeling of *boredom* so that the agent will start the creative process to explore the complexity-filled world again in seek of novelty (Gomez-Ramirez & Costa, 2017). The proactive side of this shift from exploitation toward exploration and learning is marked by the emotional state called *curiosity* (Friston, Lin, et al., 2017). In philosophy and psychology, these emotions related to knowledge exploration are called *epistemic emotions* (Pekrun, 2011; Nerantzaki et al., 2021; Vogl et al., 2021; Yanagisawa & Honda, 2023). It is true that more basic forms of affective dynamics such as emotional valence (positive-neutral-negative continuum) are proposed to play roles in the process of free energy minimization (Joffily & Coricelli, 2013). Emotions, however, are also known to reflect the precision of the predicted consequences of action in a hierarchical manner involving sensorimotor, interoceptive, and proprioceptive levels (Clark et al., 2018), and the hierarchical inference scheme (deep active inference) is applied to the principled Bayesian model of emotional valence, incorporating deep temporal models (Hesp et al., 2021). In other words, monitoring free energy dynamics elicits emotional states at multiple levels, and these emotional states may play crucial roles in free energy minimization. Basic forms of emotion such as happiness and fear may help biological agents to adapt to changes in the world via variational free energy minimization. In turn, epistemic emotions, which are related to higher cognitive process of conscious knowledge exploration and acquisition, may provide a tangible interface between deliberate intellectual learning and expected free energy minimization in rich temporal depth, connecting the higher-level future-oriented deliberate macro policies in discrete time with the lower-level automatic micro policies based on predictive coding and sensory attenuation in continuous time (Parr et al., 2022, p.100, p.201).

What can FLLE learn from these facts? At least four implications could be derived. First, since language learning is a deliberate and effortful process, temporal depth should be considered, both in terms of pedagogical planning (e.g., gradual development of different skills) and research (e.g., longitudinal tracking of learning). In this respect, the complex dynamic systems theory approach will provide valuable perspectives although it is not so much a unifying theory as a metatheory (Larsen-Freeman, 2020; Hiver et al., 2022). The notion of temporal depth will also provide a scientific approach of quantifying depth, which

will reinforce theories involving the concept of depth — such as the tertiary education concept of deep active learning and its practical applications (Matsushita, 2018; Kanazawa, 2023a) and the P4ELT practices that include deep contemplation through various methods of philosophical dialogue (Kanazawa, 2021a; Matsushima et al., 2023). Second, stepping outside the intellectual comfort zones of learners' own existing knowledge to expand the scope of their horizons will require future investment at the expense of the familiarity of the status quo. What drives this adventurous maneuver is intrinsic motivation, explainable by the mechanism of expected free energy minimization via epistemic value maximization toward exploration (Parr et al., 2022, p.36). Since self-determination and intrinsic motivation have been of central interest to quite a few FLLE researchers and teachers (McEown & Oga-Baldwin, 2019), utilizing the FEP framework may enable situating FLLE motivation theories in a broader interdisciplinary outlook surrounding motivational science (Pincus, 2023).

Third, cognition, including language learning, and emotion are interactive and complementary processes (Pezzulo et al., 2018). Their inseparability has already been proposed in FLLE via such approaches as Vygotskian theories (Swain, 2013), positive psychology (Dewaele et al., 2019), and organic philosophical insights from William James, Alfred North Whitehead, Charles Sanders Peirce, John Dewey, and Henri Bergson (Kanazawa, 2019c). In addition, emotional valence has been utilized as an independent variable in experimental investigations into foreign language vocabulary learning (Kanazawa, 2016). It was further proposed that emotional processing will result in better foreign language learning outcomes (Emotion-Involved Processing Hypothesis; Kanazawa, 2017; 2021b), which has been practically extended to foreign language learning didactics (Apple Tree Model; Kamenická, 2021). Moreover, it has been reported theoretically and empirically that negative emotional valence is related more to perceptual processing whereas positive emotional valence to deeper processing in foreign language vocabulary learning (Deep Positivity Hypothesis; Kanazawa, 2020b). With its meticulous scientific constructs and formalizations, the FEP will provide valuable insights and methodologies that could be applied to elaborating the existing findings and hypotheses in FLLE studies in a more comprehensive and systematic manner.

Fourth, epistemic emotions may well deserve more attention in FLLE studies (Kanazawa, 2022a). Epistemic emotion study could also provide an integrative theoretical foundation for previous research on foreign language enjoyment, anxiety, and engagement

(Dewaele & MacIntyre, 2014; Mercer & Dörnyei, 2020). A curious insight from the FEP is that contrary to previous findings in educational psychology (Vilhunen et al., 2022), boredom may play a positive role in knowledge exploration. Since temporally deep deliberate higher cognitive processes are related more closely with epistemic emotions than basic emotions, it would be plausible to start an hypothetico-deductive investigation by extending the Emotion-Involved Processing Hypothesis (Kanazawa, 2020a), positing that epistemic emotions themselves are deeper than basic emotions in the dynamic multileveled cognitive-emotional continuum (Kanazawa, 2022b), and that intellectual learning and acquisition would benefit more by mindfully harnessing epistemic emotions than basic hedonic emotions (Deep Epistemic Emotion Hypothesis; Kanazawa, 2023b).

5. Ode to an ab initio theory that has yet to come — 4 skills, 7 skills, CEFR-CV, Bohmian implicate order, Peircean inquiry

In this paper, the potential implications of the FEP to FLLE have been discussed. First, we have seen the relevance of FLLE and the recent cognitive scientific theory of 4E cognition, which is compatible with the FEP framework. Second, the significant role of prediction in perception and input processing has been reviewed. Third, the inseparability of perception and action as well as the trade-off between accuracy and complexity has been discussed under the unifying mechanism of variational free energy minimization. Fourth, the extended model that integrates the temporal depth and future-oriented prediction (i.e., expected free energy minimization) has been introduced. Further, we have seen how intrinsic motivation, exploration, emotional valence, and epistemic emotions are interconnectedly explainable in the FEP framework. Since the FEP is meticulously profound and ever developing in multidisciplinary vectors, this initiating paper was able to focus only on some of the most fundamental aspects in a greatly simplified manner, calling for further interdisciplinary study to operationalize the FEP theories into FLLE research and pedagogical practices. For deeper understanding of the constructs mentioned in this article, FLLE readers interested in the FEP framework are encouraged to read introductory papers and books, such as *Active Inference: The Free Energy Principle in Mind, Brain, and Behavior* (Parr et al., 2022).

On a final note, a significant meta-level implication of the FEP is emphasized, i.e., its ab initio (first principle) approach. In his seminal work, Willaim James, the father of modern psychology, discussed cognitive functions in detail while classifying them into such

categories as perception, attention, memory, and emotions (James, 1890). These Jamesian categories have widely been utilized in psychology and cognitive science literature, many treating them as isolated subsystems. This conventional approach, however, is not necessarily optimal because these categories are just one epistemological form of interpretation and thus often arbitrary, compatible only with certain sets of findings, not necessarily corresponding to distinct cognitive processes and neural correlates (Parr et al., 2022, p.197). On the other hand, the FEP provides a unifying ontology as well as epistemology. Instead of constructing a map of cognition by assembling building blocks of separate cognitive functions (perception, action, planning, emotion, etc.), it elucidates the covert first principle that permeates cognition from which the distinctified cognitive functions can be explained. Indeed, how you perceive and interpret the world depends on how you have learned to conceptually separate the world. Under the FEP's ab initio approach, dominant existing classifications are revisited because seemingly distinct functions may in fact be just different sides of the same coin, sharing the same underlying imperative and mechanism. The abstract first principle that permeates seemingly separate entities bears a striking resemblance to the multidimensional implicate order and its elusive holomovement (dynamic wholeness) in Bohmian quantum mechanics (Bohm, 1980).

Likewise, the conventional basic factors in FLLE may in fact be arbitrarily separated aspects in an inertial interpretative system. From this, previous literature derived heuristic values that are implicitly bound by their spaciotemporal situations, sociocultural needs, and epistemic affordances of the paradigm they belong to. For example, no FLLE researchers and practitioners are ignorant of the basic four skills in language learning: reading, listening, writing, and speaking. These separated categories are applied not only in academic investigations (e.g., reading study, listening study) but also in curriculum development (e.g., reading class, listening class) and language testing (e.g., reading test, listening test). There have been a number of attempts to investigate the relation of these distinct skills, for example, how do reading test scores and writing performance correlate? Surely, the four-skill approach is a straightforward way to describe the phenomenology of language usage. It is, however, doubtful whether supposing four distinct skills and constructing the general language proficiency as the conglomerate is the optimal epistemology (Figure 2).

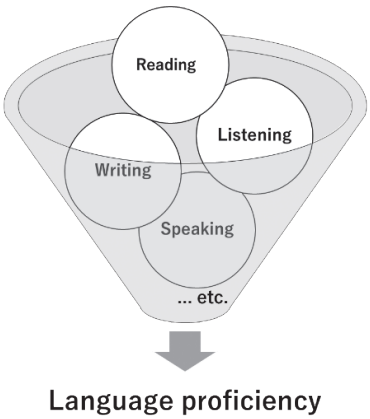

Figure 2. Language proficiency as a conglomerate of multiple separate factors

As a matter of fact, the traditional four-skill view was revisited in the new CEFR-CV, which posits reception, production, interaction, and mediation as the basic elements of communicative language activities and strategies (Council of Europe, 2020). While being operationalized for proficiency profiling, however, the insightfully reformulated categories have become more granular and complex, positing seven skills (viz., oral comprehension, reading comprehension, oral interaction, written interaction, oral production, written production, and mediation), which are further subdivided into different elements in each category. This updated system may well reflect the latest paradigm of applied linguistics, but the increased complexity may metaphorically result in going against the call of the FEP, i.e., minimizing free energy. Simple and accurate hermeneutic frameworks and guidelines will have better pragmatic values, especially concerning classroom teachers in the actual field of education who are often too busy to immerse themselves in philosophical contemplation and full-scale academic investigations. Besides, the current classification may not be immaculate, too; in a closer look, the miscellaneous elements in the category of mediation may well be tagged with other categories as well, and vice versa. Indeed, supposing a fixed set of basic categories and classifying elements (sorting-files-inside-folders approach) cannot help being arbitrary to some extent because these elements belong to a specific type of explicate order in which the implicate order was unfolded with a specific set of interpretative system among many other possible systems (Bohm, 1980). In reality, however, these elements are organically interconnected with each other in varied qualitative and quantitative degrees; or more precisely, these categories and elements are

conceptually carved out of the undivided wholeness of the implicate order. Furthermore, including a plethora of elements in hierarchical folders may also lead to the problematic saturation of concepts, on which Occam's razor should be applied to decrease the complexity while maintaining the accuracy (Kanazawa, 2019d).

The FEP's ab initio approach can work as a potentially more fruitful alternative to the sorting-files-inside-folders approach. An ab initio approach will start by trying to identify the underlying covert mechanism that permeates everything relevant in the target of the model via inductive as well as Peircean abductive reasoning (Wilson, 2023), the latter potentially initiated by epistemic emotions (Vitti Rodrigues, 2023) and compensated by heuristically serendipitous insights derived from the transient glimpse into the penetrating rationality of perception (Krishnamurti & Bohm, 1980/1985) from the existential depth (Kanazawa, 2019a). In turn, different functions will be deductively situated in the unifying model in an organic manner, which could then be tested and validated empirically in the community of inquiry (Lipman, 2003). The community of inquiry is a Peircean concept that has also been applied to FLLE (Matsushima et al., 2023). The presupposition of a first principle also echoes Peircean account of truth (Misak, 1991) — which could be compensated by the geometrical philosophy of universals as the four dimensional reality and the final abstract concepts as their proxies to be epistemically discovered rather than fabricated (Yamaguchi, 2022), and that the ascertainment of truth should be proceeded under Peircean economy of research, which resonates with the idea of free energy minimization in the FEP framework (Beni & Pietarinen, 2021). Keeping Peircean fallibilistic and synechistic spirits in mind (Peirce, 1897/1931), starting an inquiry in an ab initio approach will provide a worthwhile alternative research program, which will eventually lead to the discovery of the holistic unifying theory that has yet to come in FLLE by unfolding the underlying implicate order in a creative manner that maximizes both epistemic and pragmatic values; and it will be accomplished without losing sight of its ontologically enfolded dynamic wholeness and the permeating holomovement (Figure 3).

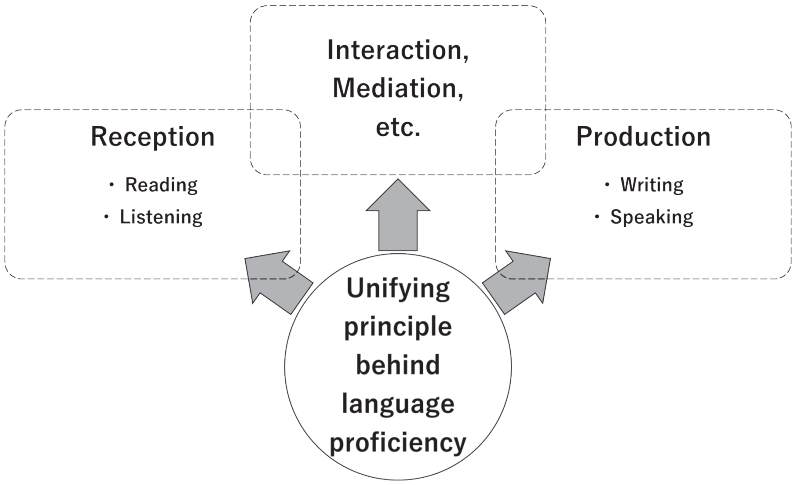

Figure 3. Language proficiency in an ab initio approach with its ontology of the underlying implicate order

Author contribution

YK has written the article on his own.

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自由エネルギー原理とその言語学習・教育への示唆：4E 認知、予測、正確さと複雑さのトレードオフ、エピステミック情動による内発的モチベーション、4 技能

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要旨

近年の認知神経科学やバイオフィジックスにおける注目すべき理論的枠組みの一つである能動的推論もしくは自由エネルギー原理（FEP）は、脳、さらには生命システムのダイナミクスの画期的な統一理論として有望視されています。この論文では、FEP のいくつかの重要な概念を非常に簡略化しながら紹介し、外国語学習研究者や教育実践者がそこから何を学べるのかを論じます。具体的には、次のようなトピックが理論的に検討されます。

(1) 身体化され、状況に埋め込まれ、現成的で、拡張された 4E 認知
(2) 遍在する予測：無意識的推論としての知覚、予測に基づく学習
(3) 自由エネルギーの最小化：知覚と行動の本質的な不可分性、正確さと複雑さのトレードオフ、CAF
(4) 時間的深さへ：期待自由エネルギー、探索を生み出す内発的モチベーション、情動価、エピステミック情動
(5) まだ見ぬ ab initio 理論にむけて：四技能、七技能、CEFR-CV、ボーム量子論における内蔵秩序、パース的探究