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From Schema to Cognitive Pathway

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Abstract
Developmental science increasingly speaks in embodied, ecological, and relational terms, yet many of its operative constructs still rely on hidden inner structures. This article responds by reconstructing Piaget's distinction between operative schemes and figurative schemas in explicitly embodied-ecological terms. Operative schemes are recurrent cognitive pathways through which activity is carried forward; figurative schemas are realised affordances within canalised cognitive pathways of participation. On this basis, the article proposes scheme-schema-affordance formations as the smallest analytically useful unit of developmental analysis and an endosystemic extension of Bronfenbrenner's model focused on the organised teaching-learning moment. Reflexive abstraction is presented as reorganising cognitive pathways, canalisation deepening them through revisiting, memory as the renewed availability of a cognitive pathway, and transferring its uptake in a new context. Illustrated through early mathematical activity, the argument concludes with a pedagogical claim: teaching is best understood as the cultivation of affordance-rich niches through which more differentiated cognitive pathways of learning and development become available.

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Introduction: The Unresolved Problem of the Basic Developmental Unit

A central unresolved problem in contemporary developmental science is that its metatheoretical commitments and its operative explanatory units are often at odds. The field increasingly describes development in relational, embodied, and ecological terms, yet still frequently explains continuity by appealing to hidden inner structures or processes. In the educational context, cognitivism has long operated as an axiomatic paradigm, treating constructs such as *self-regulation* as though their explanatory status was self-evident. Yet the growing prominence of relational pedagogy has exposed an increasingly sharp ontological and epistemological tension within the field. A clearer embodied and ecological account of child development and learning is now urgently needed. This paper is therefore motivated by the search for an adequate account of the reciprocal learning and teaching moment in preschool practice, and it also responds to a challenge recently articulated in the pages of this journal: how developmental explanation might be located in the temporal dynamics of organism-environment coactions rather than in concealed generators presumed to lie behind them (Witherington, 2025). The present argument takes up that challenge by reconsidering one of developmental theory's most persistent constructs: the schema.

Two recent contributions to human development are particularly relevant: Hutto (2025) in pressing the challenge of the "E-turn" has questioned the mainstream cognitivist assumption that cognition is always

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representational and that it takes place in the head. Tamis-LeMonda (2025), from a different but complementary direction, argues that learning is irreducibly embodied and embedded, action is the immediate impetus for learning and behaviour, and that it cannot be separated from the social, cultural, and physical environment in which it unfolds. Taken together, these interventions make it harder to retain the developmental constructs that have dominated the subject of child development psychology for decades. Few terms reveal this problem more clearly than the concept of the schema. In much contemporary developmental and educational writing, the term has widely been loosely applied as a quasi-mental structure that stores, organises, or processes experience, a term entirely at odds with the wider theoretical frame that claims to have moved towards ecological and relational accounts.

Piaget's distinction between operative schemes and figurative schemas (Piaget, 1952, 1971) is identified here as a means to resolving the issue. The aim here in applying the scheme-schema distinction was reconstructive rather than any hermeneutic recovery of Piaget, it is argued that the distinction is valuable in its own right, and it can be reformulated in a way that remains faithful to an embodied-ecological developmental science while also entering productive dialogue with recent process-relational, ecological, and sociocultural work (Gibson, 1979; Piaget, 1952, 1971; Tamis-LeMonda, 2025; Vygotsky, 1978; Witherington, 2025). In this reconstruction, operative schemes are understood as recurrent embodied cognitive pathways through which activity is carried forward, while figurative schemas are understood as the realised affordances of a canalised cognitive pathway of interaction and participation. Scheme-schema are distinguishable, but not separable: recurrent cognitive pathways leave the world differently available; the differently available world recruits recurrent cognitive pathways anew.

In distinguishing between scheme and schema, Piaget was anxious to explain the child's construction of knowledge without treating knowledge as either innate mental content nor copies of the existing world. His studies identified substantial evidence of progressive knowledge organisation-reorganisation, error, experimentation, coordination, and invention. He required a unit that would help him describe how organised knowledge grew from action. The notion of "schemes" fulfilled this primary purpose, sucking, grasping, retrieving, and could be considered as discrete operations rather than as concepts in the child's head, available to be applied. But as soon as schemes become combined and coordinated into complex operations, and even more obviously when later they become symbolised and reflected upon, he argued that there must be some complementary figurative "schema." All too easily at this point, schemas may be assumed to provide the very hidden mental objects or representations Piaget sought to avoid. But that is not how Piaget understood them, he considered schema as the emergent systemic structural *form* of developing combinations and coordinations of schemes.

> *"What is commonly called memory, then, once rid of the remnants of facultative psychology, is simply the figurative aspect of the systems of schemes as a whole, from the elementary sensorimotor schemes in which the figurative aspect is perceptual recognition, to the highest schemes. . ."* (Piaget and Inhelder, 1973, p. 81)

Schema's should not be considered representations standing behind action. If we consider the analogy of the *rigidity* of a triangular structure, we can appreciate it as an emergent system property of the particular configuration. Similarly, schemes are the operative members, and schema are the structures that appear when these members are repeatedly recruited together. Schemas provide the patterned constraints and possibilities for action in the world.

From this perspective, schemas provide emergent forms of availability for novel applications of the child's schemes. To take a concrete example of the "containing" frequently observed in the nursery, if we consider a child who takes delight in piling objects into boxes, pouring sand and water into buckets, climbing themselves into cardboard boxes, and wrapping objects in fabric, they are not merely repeating separate schemes. A broader *containing schema* is becoming visible as they apply their *containing scheme* in all these different contexts. The schema is not some internal representation of "containment"; it is an emergent field of relations in which containment has become a *revisitable* way of organising their play. The substantial schematic literature in early childhood education is replete with further examples and pedagogic guidance on how educators may support these early schemes (albeit referring to them as "schema"). Athey's (1990) work established the importance of observing children's repeated forms of activity as evidence of continuity in their thinking, while Nutbrown (2006) developed this into a pedagogical argument for attending to children's "threads of thinking" as they are expressed across play, representation, and talk. Most notably in the UK and Australasia, but also increasingly in the USA (Bernt-Santy, 2025), early childhood educators are

encouraged to notice what children repeatedly do, to resource those interests, and to create conditions in which they may be extended, revisited, and connected with wider learning. Siraj-Blatchford and Brock (2016), and Dipper and Siraj-Blatchford (2024) apply Vygotsky (1978, p. 102) in identifying the schematic "self-scaffolding" taking place in the play of children operating in their *zone of proximal developmental flow*. What remains relatively undeveloped is an associated explanatory and analytic framework capable of showing how such recurrent activity becomes developmentally productive. A central objective of this paper is therefore to contribute such a framework.

In educational analysis, a central concern has been to provide better understandings of the possibilities and constraints for action sustained in episodic teaching-learning moments. In the following account, adopting an ecological perspective, these moments will be described as scheme-schema-affordance formations (SSAFs), with their pedagogic development best understood as the cultivation of an educational niche. The idea of "affordance" is required in the model at this point in acknowledgement of the influence of the wider environment. Gibson (1966, 1979) first coined the term because he needed a noun to describe the relational possibilities that open up in interactions between an organism and its environment. He was concerned that traditional accounts of perception generated an explanatory problem by treating perception as the internal reconstruction of sensory inputs. He sought to dissolve, rather than solve, this problem by reconceiving perception as a *relational event*: an organism-environment relation through which possibilities for action become available. In the account offered here, these "action possibilities" may be understood broadly as operative engagements that include bodily movements, orientations, attentions, but also the use of signs, tools, models, and social practices as well.

Though developed from an educational concern, this reformulation has wider relevance for developmental science. The SSAFs referred to are not understood as private mental contents, nor isolated behaviours, nor environmental triggers, but they are understood as episode scale achievements in which recurrent cognitive pathways, patterned availabilities, and affordances are jointly recruited. This offers a means of analysing developmental formation at a scale small enough to illuminate moment-to-moment process, yet rich enough to connect local episodes to routines, practices, and historically sedimented cultural worlds (Bronfenbrenner & Morris, 2006; Gibson, 1979; Vygotsky, 1978). It also provides a framework for defining, within Bronfenbrenner's wider project, an endosystemic level of analysis focused on the organised teaching-learning moment itself.

This reconstruction alters how continuity itself is described. If development is approached through SSAFs, continuity can be treated as the canalisation of revisitable cognitive pathways of participation rather than as the accumulation of inner contents. The language of canalisation is used here in a developmental sense derived from Waddington's account of cognitive pathway formation, extended in developmental psychology by Gottlieb's notion of experiential canalisation, and taken up in contemporary neuroscience as a way of thinking about the relation between plasticity and the entrenchment of cognitive pathways (Carhart-Harris et al., 2023; Gottlieb, 1991; Waddington, 1957). Waddington's account of canalisation envisaged an epigenetic landscape that becomes channelled along pathways that are increasingly likely to be re-entered and maintained despite variation in circumstances. Here, the term is applied in this sense, but also consistent with more recent accounts of developmental plasticity (de Jong, 2005; West-Eberhard, 2003). It is important that we avoid any connotation of the passive following of any pre-given routes. We can usefully consider a stream cutting its pathway through a complex and changing landscape. The terrain and geological structure will shape the flow, but the flow also erodes, deepens, diverts, and sometimes overflows the terrain. Heavier or more sustained rain may open channels that a lighter flow would not. Similarly, developmental pathways are not mechanically predetermined. They are formed, stabilised, and constrained through repeated organism-environment relations, in which activity itself contributes to the making of the path. Applied to this canalisation analogy, the affordances shaping our route along any particular pathway will depend on the relation between features of the environment; the gradient, vegetation, growth, obstructions, saturation, and geological substrates; and both the historic and contemporary volume, force, recurrence, and velocity of the flow. The route taken is therefore neither imposed by the landscape alone, nor generated by the flow alone; it emerges through their continuing relation.

A related stream metaphor appears in Thelen's (2005) dynamic system account of development, where the stream both reflects its developmental history and continually reshapes its own course. The present formulation presents this imagery through Waddington's (1957) concept of canalisation, using it to describe pathways progressively formed through repeated

organism-environment activity while remaining open to redirection.

A further consequence of adopting the SSAF model is pedagogical. If developmental structures take shape through the canalisation and reopening of child-environment cognitive pathways, then teaching is not well described as the delivery of content into an inner architecture. Nor is it adequately captured by the mere elicitation of visible performances. It is better conceived as the cultivation of affordance-rich niches in which more differentiated structures of action and sense can emerge, be revisited, and become available for extension. In this respect, the argument points towards an emergent-structural pedagogy of the sort first outlined by Piaget (1948, 1973) where he argued that schools should recognise that "*to understand was to invent, or to reconstruct by reinvention.*" See also Deniz-Prinzhorn and Grize (1966), and Siraj-Blatchford (2022). The account developed here extends these constructivist insights further in an embodied and ecological direction where invention is not treated as the achievement of an individual subject, but as an emergent outcome of the SSAFs through which pathways of action, attention, and meaning become canalised, re-entered, and transformed.

Why the Concept of "Schema" Became a Conceptual Liability

There have been both historical and conceptual difficulties associated with the application of Piaget's distinction between operative schemes and figurative schemas. Part of the difficulty has been that in Piaget's (1961) French schème was often translated into English as schema, making it harder for the academic literature to preserve the difference. Piaget and Inhelder (1973) themselves later found it necessary to clarify the issue, and Hans Furth made an important effort to unravel some of the misunderstandings that had accumulated around it, drawing on texts not then available in English, and on Piaget's responses to some of the emerging secondary literature (Driscoll, 2000, p. 189; Furth, 1967, 1969). Recovering that distinction is essential to the present argument, because without it developmental continuity is too easily relocated into a single quasi-mental construct.

The distinction is especially important because it locates developmental order within lived child-environment relations rather than behind them. Figurative "schemas" provide the means by which realised affordances allow situations to become actionable. It is through the recurrent cognitive pathway of operative "schemes" that situations are entered, varied, sustained, and transformed. What matters is that the two differentiate two aspects of one ongoing organisation of activity. Furth's particular concern with this was associated with interpretations of symbol formation. He found that symbolic activity was often treated as if it straightforwardly demonstrated the emergence of internal representational content. Furth's reading of Piaget complicated that assumption by suggesting that symbolic thought could not be adequately understood without attention to the developmental organisation from which it arose. The issue was not whether symbols involve generalisation; it was how such generalisation becomes possible in development, and whether it should be attributed to a pre-given inner schema or to a history of enacted relations that gradually make new forms of figurative organisation possible. In that respect, the mistranslation problem had consequences far beyond vocabulary. It affected how the movement from action to symbol, and from practical cognitive pathway to figurative thought, was understood in the first place.

Across popular developmental, educational, and psychological discourse, the concept of schema has increasingly come to be used to denote something like an inner template: a mental form through which experience is sorted, organised, stored, or retrieved. That shift has brought a certain convenience. It has offered a compact way of speaking about continuity, recognisability, and the evident bearing of prior participation on present activity. Yet it has also altered where developmental explanation was thought to reside. What had been a distinction within lived organisation has been gradually recast as a designation for a putatively internal arrangement presumed to stand behind activity and give it form. In this way, the translational blurring of scheme and schema fed into a broader theoretical drift back to Cartesian inner architecture.

The drift matters because it has relocated the explanatory force. Once schema was treated as an inner structure that preceded and organised action, developmental continuity appeared as the expression of what the child already carried within them rather than as the gradual canalisation of cognitive pathways. The burden of explanation shifted from participation to hidden architecture, from cultivated uptake to inferred contents. Recognition, recall, and transfer then seem to arise because an internal format had been activated, rather than because a previously enacted way of proceeding had become available again in a new encounter. But these notions of hidden developmental processes presumed to

sit behind observable activity, and/or to generate it from elsewhere have increasingly been subjected to critique (Witherington, 2025).

From an education perspective, the difficulty is much more than philosophical. It has implication for how learning and development are themself conceptualised. If continuity is explained through internal schemas, then the constitutive role of materials, spatial arrangements, temporal rhythms, co-participants, and historically sedimented practices is pushed towards the margins. The "niche," the field of affordances where teaching and learning are cultivated, appears as background rather than as directly constitutive.

Reconstructing Operative Schemes and Figurative Schemas

If the problem with schema discourse has been that it has relocated developmental continuity into an inferred inner structure, the reconstructive task must be to re-specify schemes and schemas as aspects of lived child-environment activity. This requires more than replacing one set of terms with another. It requires a shift in explanatory orientation. Development must be approached not as the organisation of inner contents later expressed in action, but as the progressive formation of cognitive pathways within relations among body, materials, co-participants, and with the wider niche (Gibson, 1979; Piaget, 1971; Vygotsky, 1978).

Operative schemes must be understood as recurrent embodied pathways' through which activity is carried forward. They are not hidden rules, symbolic programs, or internal procedures waiting to be executed. They are the repeatable organisation of action itself: reaching, enclosing, matching, aligning, balancing, waiting, orienting to another's gesture etc. (Piaget, 1952, 1971). Their continuity lies not in a detachable script housed somewhere inside the child, but in the re-enactable patterning of participation across episodes.

Figurative schemas are not stored mental pictures or static internal images. They refer instead to the experiential structuring through which something is grasped, sorted, traversed, answered, filled, aligned, or otherwise open to action (Piaget, 1971; Piaget & Inhelder, 1973). Gibson's work has helped us appreciate that a gap may stand out as crossable, a container as fillable, a row as extendable, a balance as correctable, a sequence as repeatable, or a social exchange as answerable. What is figurative here is not a private image detached from action, but the way form becomes available in lived relation. Figurative schemas describe how the world is encountered as having shape, direction, contrast, and possibility for ongoing participation.

The distinction between operative schemes and figurative schemas is therefore analytic rather than ontological. It does not divide development into two separate kinds of entity, but differentiates two aspects of one real developmental formation. The ontological claim being made here is for scheme-schema-affordances that provide a relational unit in which operative pathway, figurative availability, and a realised affordance hold together within the niche. It does not divide development into an active mechanism on one side and a passive representation on the other. It allows us to appreciate a *reciprocity* that is internal to the developmental process itself. Recurrent pathways leave the world differently available; the differently available world provides new recurrent pathways. The child who is repeatedly "containing," "transporting," or "positioning" objects, as is frequently observed in homes and preschools (Athey, 1990; Nutbrown, 2006; Siraj-Blatchford and Brock, 2016), is not simply being observed to perform the same act again. The world has become available as containable, transportable, line-able, continuable, and extendable, and that very availability solicits further use of the schemes. Equally, the child who revisits a see-saw or other "balance" apparatus does not merely remember their prior response. The relation of weight, equivalence, and correction has become newly available in experience, and this availability recruits adjustment, comparison, and renewed variation. In this sense, schemes and schemas are mutually constituting aspects of the cognitive pathway formation.

This reconstruction also clarifies the status of "stability," a term often applied in dynamic systems and process-relational accounts, and in educational self-regulation research which often treats stability as the mark of an enduring individual capacity. Here, we resist the causal assumption, seeing it rather as a descriptive outcome of a history in which certain cognitive pathways have become more available and dependable in participation. To say that a child now recognises a route or method, a quantity pattern or a turn-taking sequence is to say that the world has become available in a newly acquired way through prior participation. The explanatory burden is firmly with the developmental history of the relation, not with any inferred inner archive or capacity.

Figure 1 presents the proposed SSAF model in its educational form. The three interlacing circles represent the child, the educator, and the material-cultural

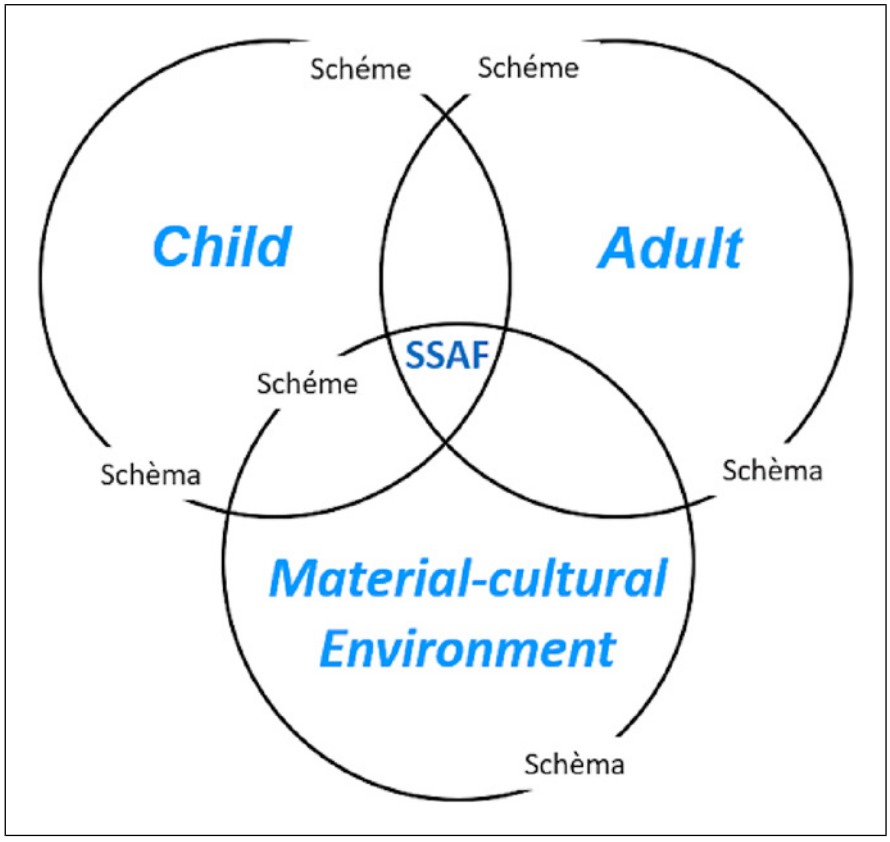


Fig. 1. Educational niche.

environment. The point is not that these are three separate factors later brought together, but that the teaching-learning moment is constituted through their temporary interlacing. The centre of the figure, labelled SSAF, marks this momentary relation: a scheme-schema-affordance relation in which a pathway of action, a realised affordance, and the organised conditions of the niche are recruited together. The outer boundary is labelled educational niche to indicate that the niche is not one component among others. It is the organised affordance field constituted through the relation of child, educator, and material-cultural environment. In this sense, the niche names the cultivated whole within which teaching and learning become possible. We will return to this model below and elaborate it to include the temporal dimension: as SSAFs are revisited, they may be deepened, stabilised, and made more accessible. What is canalised is not an inner content alone, but a cognitive pathway of participation that leaves both bodily and environmental traces, and becomes available again in later learning and development. The figure is deliberately simplified, to clarify this paper's central claim: that the reciprocal teaching-learning moment is best understood relationally, within an educational niche, rather than as the expression of any internal competence, or any effect of an external input.

The Scheme-Schema-Affordance Formation

An embodied-ecological account requires a unit of analysis that cannot lie wholly on the side of the child, nor wholly on the side of the material or the social and cultural environment. It must be sought in the organised relation through which a cognitive pathway is both enacted, and a world becomes available.

The SSAF provides, at the level of a single teaching and learning episode or moment, a means of appreciating a developmental achievement in which recurrent cognitive pathways, recurrent experiential patterns, and real possibilities for action are jointly involved. Affordance here has not been added as a third element to an already completed pair, but to make explicit what the earlier reconstruction already implies: schemes and schemas become developmentally significant only in, and through, a world that offers possibilities for uptake.

Affordance is therefore not an optional background condition to which an already formed child later responds. Nor is it a property belonging to the environment alone. It is the action possibility that exists in the relation itself, as a feature of the interacting child and environment (Gibson, 1979). The formation is a momentary organisation in which that possibility has been taken up through specific pathways of participation within the niche.

A simple learning and developmental episode will clarify what is involved. Consider a child working with buckets, sand, and a balance apparatus. The child fills, lifts, pours, pauses, compares, watches one side tip, adds more, removes some, and returns to the task. These are not merely motor acts. Within the same episode, the situation becomes available as one of more and less, equivalent or not, of correction, containment, overflow, and adjustment. At the same time, the materials themselves participate in the event: the balance tips, the buckets hold or spill, the surface supports, the sand flows, and the arrangement solicits comparison. What develops here does not lie solely in the child and solely in the adult who provided the apparatus and/or may be present. It lies in the organised relation through which recurrent cognitive pathways, patterned availabilities, and real affordances recruit one another.

The value of the proposed SSAF unit is that it resists three popular reductions at once. Firstly, it resists methodological individualism. Development does not have to be explained by locating an inner mechanism in the child and then treating the environment as a source of inputs. The affordance is not outside the unit but constitutive of it. Secondly, it resists environmental determinism. The material arrangement does not cause development simply by being present; it becomes developmentally consequential only insofar as its possibilities are taken up through coordinated activity. Thirdly, it resists reducing culture to a remote contextual layer. Culture matters because it is sedimented in the arrangements, routines, tools, and expectations through which every SSAF is cultivated. A counting routine, a picture book, a balancing task, or a shared repair activity is not merely the backdrop for an internal competence. It is a historically shaped niche in which particular pathways become more or less available (Bronfenbrenner & Morris, 2006; Vygotsky, 1978). This is crucial in relation to inclusion and the education of ethnic minority learners, because the niche itself may either narrow or widen the affordances through which culturally and linguistically diverse forms of participation can be taken up.

This way of specifying the SSAF also helps clarify why developmental analysis must be sensitive to the temporal dimension of episodes. A SSAF is not a static or timeless structure. It is a formation that appears and may stabilise, break down, and be repaired, and very importantly it may become available again in revisiting. Its developmental significance therefore lies not only in what it contains, but in how it is carried forward, interrupted, varied, and renewed across time. In this respect, the proposed unit is small enough to illuminate moment-to-moment organisation, yet rich enough to connect local episodes with broader histories of participation. It gives developmental theory something more precise than either isolated behaviour or abstract structure: a way of defining how cognitive pathways are actually enacted in the living relation between child and world.

The proposal also provides support for and a reframing of Piaget's conception of reflexive abstraction. What is abstracted[1] is not a disembodied representation lifted free of activity, but a reorganised relation made available through participation. A child revisits an established operative cognitive pathway in the face of a newly realised affordance; the relation is varied, reworked, and carried forward at a different level of organisation. In this sense, reflexive abstraction may be understood as the cyclical reorganisation of schemes and schemas in relation to affordances: not the replacement of action by thought, but the reworking of a cognitive pathway through which the world becomes newly available.

A further strength of the SSAF proposal is that it makes transfer and novelty more intelligible without invoking the movement of inner contents across contexts. If learning and development proceed through the formation of scheme-schema relations, then continuity does not depend on retrieving an invariant representation whenever a similar situation arises. Rather, a historically formed cognitive pathway may be reenacted, varied, and extended when a new situation affords an analogous line of participation. The child who has repeatedly encountered balance, correspondence, or containment in one material arrangement may later find these relations available again in another. Developmental continuity is therefore better understood as the growing

[1]Abstraction *is often understood as denoting something beyond the body. Yet to "abstract," in a more literal sense, is to draw something out from one context so that it may be taken up in another. Reflexive abstraction may therefore be understood here not as a departure from embodied participation, but as the reorganisation of a pathway such that a relation that is at first realised in one situation becomes available for revisiting, variation, and extension in another.*

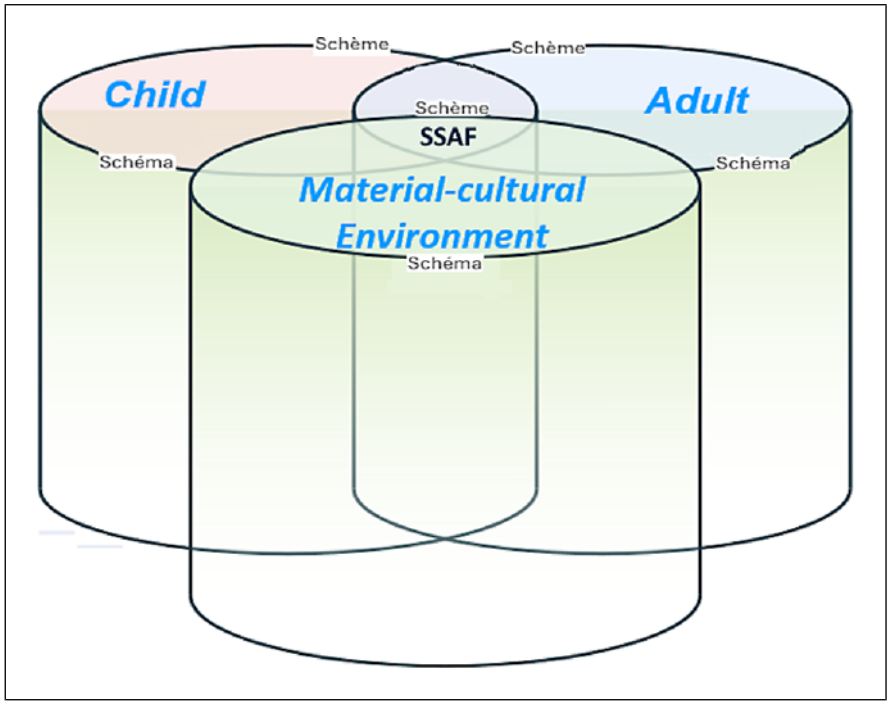


Fig. 2. Educational niche extended.

portability of cognitive pathways across families of affordance relations than as the transport of stored contents from one setting to the next.

Canalisation, Memory, Transfer, and Self-Regulation

Figure 2 illustrates the SSAF process in explicitly chronosystemic and educational terms. Child, educator, and the material and cultural environment are shown as interlacing streams extended through time, so that what deepens is not an isolated event but the history of their repeated participation. The vertical depth of the figure represents the temporal deepening of cognitive pathways through revisiting, sedimentation, and renewed uptake. In this respect, Bronfenbrenner's chronosystem is no longer treated as a contextual layer surrounding development, but as the depth dimension through which participation is repeatedly enacted, stabilised descriptively, and transformed.

While the language of canalisation applied here is echoed in contemporary neuroscience as a way of thinking about the entrenchment of plastic cognitive pathways over time, repeated participation leaves more than synaptic and wider neural traces, these constitute only one material stratum of a wider cognitive pathway that also extends across physical development, posture, movement, perception, tools, routines, co-participation, and the organised niche itself. Pathways are also deepened affectively and not through repetition alone, and the quality of the child's relation to the situation is also significant. The developmental deepening of a pathway is always affectively modulated. Vygotsky's (1994) notion of perezhivanie may be applied to describe the process through which cause canalisation becomes more or less compelling, sustainable, and available for revisiting according to the child's prior affective, cognitive, social, and developmental experiences. As will become clearer in what follows, this language of traces matters because it bears directly on how memory, transfer, and what is often described as self-regulation should be understood.

Memory appears differently once continuity is approached in these terms. It need not be conceived as retrieval from an autonomous inner archive in which developmental contents have been preserved and stored. It may instead be understood as the renewed availability of canalised cognitive pathways, consistent with Piaget's claim that memory is "the figurative aspect of the *systems* of schemes as a whole" (Piaget & Inhelder, 1973, p. 81). What returns in memory is not a mental object transported intact from the past into the present, but a way in which the world and one's own possibilities within it become available again through prior participation. Neural traces matter here, but as bodily traces within a

wider developmental history, not as the solitary location of memory. To remember, in this sense, is not first to inspect an inner content and then apply it to the world. It is to find oneself once again afforded the opportunity to enter a previously cultivated relation: a route is again traversable, a quantity pattern again discernible, a routine again answerable, a line of balancing or correspondence again open to uptake.

This reformulation also clarifies why memory in practice is so often inseparable from place, rhythm, tools, and co-participants. Recollection is not only something that happens "in" the child and is then outwardly expressed. It is frequently recruited through the reappearance of material arrangements, sounds, aromas, familiar gestures, recurrent temporal sequences, and shared forms of activity. A particular table layout, the feel of a container, the cadence of a counting routine, or the reintroduction of a balance apparatus may help reopen a cognitive pathway because the original developmental formation was never sealed off from such conditions in the first place. Memory is therefore better treated as a relational achievement of renewed availability than as the retrieval of self-sufficient content.

Transfer, likewise, can be respecified without appealing to the movement of stored representations across contexts. If developmental continuity lies in canalised pathways, then transfer is not the export of an invariant inner structure from one setting to another. It is the reenactment and extension of a previously formed cognitive pathway when a new situation affords an analogous line of participation.

This account also helps explain novelty. A cognitive pathway that has become more available through prior enactment does not merely reproduce itself unchanged. Because it is a cognitive pathway rather than a stored form, it can be inflected, extended, and reorganised as new affordance structures are encountered. Developmental continuity is therefore compatible with transformation. Indeed, transformation depends upon continuity of this kind. Without some re-openable cognitive pathway, there would be nothing to vary, extend, or reorganise. Novelty emerges not from the sudden appearance of a wholly new inner structure, but from the reworking of previously canalised relations in newly organised circumstances.

At this point, what is often referred to as a child's "self-regulation" can also be redescribed more precisely. Capacities such as waiting, pausing, returning, inhibiting an immediate movement, or sustaining attention need not be treated as the expression of an inner executive mechanism that first regulates behaviour from within. They may instead be understood as the canalised availability of cognitive pathways cultivated through repeated participation with others, with tools, and within organised routines. A child's growing ability to wait, to hold a line of activity, or to recover from interruption is better understood as the historical deepening of relational cognitive pathways that have left bodily, including neural traces, and that can now be reopened with increasing reliability. Self-regulation is more adequately considered an outcome of canalised participation rather than as any inner causal source.

This way of thinking has a further consequence for how the pedagogic encounter is understood. In educational settings, what is often at stake is what, in early childhood research, has been described as sustained shared thinking (Siraj-Blatchford et al., 2002), and in other educational contexts as dialogic teaching (Alexander, 2018), an educationally effective (and affective) "meeting of minds." From an SSAF perspective, the achievement of such an encounter is not a hidden cause that explains learning and development. It is the descriptive outcome of a history in which certain cognitive pathways have become more readily reopened, sustained, and shared. Equally, breakdown is not simply failure; SSAF analysis may reveal where canalisation is still partial, fragile, or dependent on particular supports. Repair then becomes educationally significant because it is one of the means by which a shared cognitive pathway is deepened, widened, or reorganised. Learning and development are better understood as cognitive pathways of participation that are gradually cultivated, interrupted, renewed, and extended in the classroom and nursery within a living educational niche.

Once continuity, memory, transfer, and self-regulation are approached in this way, developmental analysis is no longer confined to the episode in isolation. Canalised cognitive pathways are formed within histories of participation, and those histories are always more than individually determined. They are shaped by recurring routines, culturally sedimented tools, organised environments, and the participation of others who help hold open, vary, and sustain lines of activity.

From Learning and Teaching Moments to Cultural Practice

The importance of the SSAF lies, in large part, in its capacity to scale, as previously noted, within Bronfenbrenner's broader project, it suggests an endosystemic extension, and cultural and historical formation may also

be taken analytically into account, not as an external context later added to the child's development, but as constitutive of the niche itself. Tools, symbols, genres, expectations, and divisions of labour are not suspended above developmental episodes. They are sedimented in the very material and interactional arrangements through which affordances become available. In this respect, Vygotsky (1978) and Engström (2001) cultural-historical activity theory is particularly relevant. What cultural-historical activity theory identifies as tool mediation, rules, community, and division of labour may be understood here as historically organised features of the niche through which cognitive pathways of participation are canalised and extended. Siraj-Blatchford and Manas (2026) have applied this framework in their forthcoming study of socio-dramatic play. What the present account adds is a finer grain of analysis. It shows how the developmental significance of a proximal process may be described through the SSAF that it cultivates, links, interrupts, and renews.

Seen in this way, developmental analysis can move between levels without reducing one to another. The episode remains indispensable because development is always enacted there, in the temporal organisation of cognitive pathway, availability, and uptake. But the episode is never enough on its own, because it is already patterned by routines, by materials prepared in advance, by culturally sedimented meanings, by the expectations of co-participants, and by the wider institutions within which such encounters recur. The SSAF offers a way of relating local developmental formation to broader cultural practice without either dissolving the former into the latter or treating the latter as a mere backdrop (Lerner et al., 2026; Witherington, 2025).

This scaling also clarifies why pedagogy cannot be reduced either to transmission or to facilitation understood as mere non-interference in the context of early childhood play. If cultural practices participate in the organisation of affordance fields, then educational action is always involved in the cultivation of the niches through which developmental cognitive pathways are canalised. The educator is not simply a source of input, nor merely an observer of spontaneous emergence. The educator participates in arranging materials, preserving or varying rhythms, introducing symbolic means, joining attention, naming contrasts, and sustaining lines of activity long enough for new forms of cognitive pathway and world availability to emerge. Teaching, in this sense, belongs within the developmental field itself. It is one of the means by which cognitive pathways are made more or less available for revisiting and extension (Bril, 2025; Tamis-LeMonda, 2025).

This point may be further illustrated if we take an example from early mathematics. Mathematics provides a particularly demanding test of this argument because mathematics is so often treated as the paradigm case of abstract content, internal competence, or symbolic representation. If the reconstruction proposed is to carry theoretical weight, it should be able to illuminate mathematical development without retreating to those assumptions. The question, then, is not whether mathematical activity eventually involves symbols, abstraction, or generalisation. It clearly does: the question is how such activity first becomes available, revisitable, and extendable in learning and development. The next section takes up that question directly.

Early Mathematical Activity as Cognitive Pathway Formation

Consider a young child playing at the preschool water table. The educator has made the water facility available and has placed differently sized containers within it so that the child may be supported towards emerging notions of volume and capacity. Yet the mathematical significance of the scene does not lie in the educator having transmitted these notions in advance, nor in the child's possession of them as hidden concepts awaiting expression. It lies in the organised niche itself: a materially structured, pedagogically intended setting in which some relations are made more available than others and in which the child may revisit, vary, and extend lines of participation.

At first glance, the episode may appear to involve only practical handling. The child dips, fills, lifts, tilts, pours, spills, stops, refills, compares, repeats. But these are not merely isolated motor acts. They form a recurrent operative cognitive pathway through which the activity is carried forward. The child begins to return to some actions rather than others: filling one vessel fully before pouring into another, watching the water level rise, stopping at overflow, noticing that one container empties into another with some water left over or with some space still remaining. Repetition here does not simply produce familiarity. It organises a cognitive pathway of participation in which certain relations become more available for renewed uptake.

On the figurative side, the water area becomes available in a correspondingly structured way. The containers do not remain mere objects; they are

encountered as fillable, pourable, comparable, overfillable, and perhaps, under some conditions, equivalent. Water level becomes noticeable as rising, falling, enough, not enough, too much, or just fitting. One container may begin to stand out as "holding more," another as "not enough," another as "nearly the same." Volume and capacity are not yet present as detached conceptual objects, but nor are they absent. They are realised in the child's encounter with the situation as features of the world that can be revisited and varied in action.

The developmental event therefore lies neither in the operative sequence alone nor in the realised affordance alone. It lies in their relation within the educational niche. The water affords visible transformation; the containers afford filling, transfer, comparison, and overflow; the arrangement affords revisiting; and the educator's prior preparation of the environment ensures that these relations can become salient. What is formed is a scheme–schema relation through which particular affordances are repeatedly realised in participation. The mathematical significance of the episode lies in this relation, not in a hidden structure presumed to stand behind it.

The educator's role is therefore crucial, but not in a transmissive sense. The point is not that the child discovers volume and capacity in a wholly unstructured environment, nor that the educator implants those notions from outside. Rather, the educator has cultivated a niche in which these relations are more likely to emerge as the child acts. The choice of containers, their different sizes and shapes, the availability of repeated filling and pouring, the possibility of overflow and comparison, and the pacing of the encounter all help organise an affordance field oriented towards volume and capacity. In this sense, the pedagogic intention is materially present in the niche before it is ever verbally stated.

Across revisiting, this cognitive pathway may become progressively canalised. The child may return more quickly to previously noticed relations, anticipate that one container will overflow before another, select a larger vessel in expectation of what will happen, or attempt to make one container hold "the same" as another by repeated filling and transfer. What is deepening here is not a stored inner representation of capacity, but a reopenable cognitive pathway through which relations of more, less, enough, remainder, and equivalence become increasingly available. Repeated participation may also leave bodily, including neural traces, but these remain consequences of the cognitive pathway rather than hidden causes standing behind it.

What is reorganised through revisiting is not an abstract symbol detached from the activity, but the relation itself. The child does not simply repeat an earlier pouring act; the child re-enters an already available cognitive pathway under slightly altered conditions and, in doing so, reorganises it. One vessel that previously appeared only as fillable may now appear as "holding less"; another may become the measure against which others are compared. In this way, a more differentiated route through the niche is formed. The movement towards abstraction is continuous with sensory motor intelligence rather than replacing it.

Symbolic mediation may then enter the scene without severing the child from this embodied history. The educator may provide containers, at times all of equal capacity and at other times varied, and they may prompt the naming of particular some "full," "empty," "more," "less," "same," or "too much." They may also invite comparison by word or gesture; they may mark levels; they might suggest pouring from one vessel into another again or later connect the experience with counting, measuring, or drawing. Such symbolic means do not arrive as supplements to an already complete inner understanding. They reorganise the affordance field from within. Naming may render a contrast more readily revisitable; marking may preserve a relation for return; counting may stabilise a comparison; later measurement may extend the cognitive pathway into more formal mathematical practice.

This is why early mathematical learning and development are better understood here as cognitive pathway formation than as concept acquisition in the traditional narrow sense. To say that the child is beginning to understand volume or capacity is not to posit an inner mathematical object that has now been installed. It is to describe the emergence of a revisitable route through which such relations can be enacted, noticed, varied, and later reconstructed at increasing levels of generality. Mathematical abstraction, on this view, is not the departure from embodied participation but its further reorganisation.

The force of this example reaches beyond mathematics itself. It shows that even where development is often assumed to concern abstract knowledge most directly, the relevant unit remains the organised relation among operative cognitive pathway, realised affordance, and niche. Volume and capacity do not stand outside this account as pre-given concepts awaiting expression. They emerge through the canalisation and reorganisation of cognitive pathways within a deliberately prepared,

materially structured, and pedagogically sustained field of participation.

Practical application of underlying principles is currently being applied in studies associated with education for sustainable citizenship and socio-dramatic play reported in Siraj-Blatchford, 2006 ab. Previous work was featured in a special edition of the UK Association for Science Education (ASE) *Emergent Science* (Siraj-Blatchford, 2022; Yewman, 2022) and in numerous SchemaPlay™ publications (Siraj-Blatchford and Brock, 2016)[2].

Implications for Developmental Theory, Method, and Pedagogy

The argument developed here has implications that are theoretical, methodological, and pedagogical. At the theoretical level, it suggests that developmental science should be more cautious about terms that name achieved outcomes as if they were causes. Terms such as representation, self-regulation, stability, and competence can be descriptively useful, but they become misleading when they are treated as hidden sources from which developmental coherence is presumed to flow (Hutto, 2025; Witherington, 2025).

This caution is not only theoretical. It also has pedagogical implications. When educators draw on terms such as self-regulation, competence, or even schema as though they named hidden causal capacities, there is a risk that variation in participation will be read too quickly as a lack within the child rather than as a question about fit, support, affordance structure, and the organisation of the teaching-learning encounter. In such cases, explanatory overreach can encourage an over-diagnostic pedagogy, displacing attention from the cultivation of the niche to the presumed remediation of internal child deficits.

The present reconstruction does not deny that children come to act in more organised, reliable, and portable ways. It questions where that organisation is said to reside and how it is said to arise. If developmental continuity is better understood as the canalisation of revisitable cognitive pathways of participation, then the explanatory burden shifts away from inferred inner governors and towards the historical formation of relations among body, niche, tools, co-participants, and the patterned availability of the world (Gibson, 1979; Gottlieb, 1991; Piaget, 1971).

Another implication concerns the status of bodily traces, it has been argued that repeated participation leaves material consequences in the body, and among them synaptic and wider neural changes shaped through experience-dependent plasticity. Neural change matters here as a consequence and sedimentation within cognitive pathway formation. But to say this is neither to reduce development to the nervous system nor to bypass it in favour of a purely behavioural or environmental description. It is to place neural traces where they belong: within a broader developmental history that also includes the child's physical development, posture, movement, perception, tools, rhythms, routines, and the organised niche (Fu & Zuo, 2011; Kolb & Gibb, 2011). This positioning has particular force for the reconceptualisation of memory: "trace" must be understood as distributed across the bodily and environmental history of participation rather than collapsed into an inner archive alone (Piaget & Inhelder, 1973).

Methodologically, the argument points towards a finer-grained attention to developmental episodes and their histories. Education policymakers have developed a particular penchant for interventions that assume single causal mechanisms can be isolated through normative statistical analysis and then authorised through effect sizes. Such measures may summarise patterned associations, but they do not, by themselves, explain the developmental organisation through which particular children come to act, persist, disengage, or flourish. The developmental significance of an event often lies in the joining of materials, timing, co-participation, affective tone, and cultural means within a living niche. To study development adequately is therefore to remain close to the organisation of such episodes while also tracing how they are recruited into longer histories of participation (Tamis-LeMonda, 2025). Such an orientation would not exclude measurement, coding, or the study of neural change, in fact a wide variety of methodologies may be applied (Siraj-Blatchford, 2024, 2025). But it changes the questions to which these methods are addressed. The issue is no longer simply what a child can do, but how a niche supports, narrows, widens, or redirects particular forms of doing, noticing, returning, and carrying forward (Bril, 2025; Tamis-LeMonda, 2025; Witherington, 2025). Dipper and Siraj-Blatchford (2024) and Siraj-Blatchford and Manas (2026) report on early attempts that have been made to show how occupation-oriented participation realised through microgenetic participation mechanisms; moment-by-moment coordination, affective timing, approval seeking, and the embodied dynamics of protest and repair may become established

[2]See https://johnsb.org.uk/publications/.

across episodes, and how adult practice can support "retuning" rather than compliance. The SSAF model presented here takes this analysis a stage further to more fully integrate the environmental contribution.

The pedagogical consequences of the argument point towards what may be called an "emergent-structural pedagogy." Such pedagogy is concerned with cultivating the material, temporal, interpersonal, and symbolic conditions from which more differentiated structures of action and sense may emerge, become available for revisiting, and be extended across new situations (Bril, 2025; Shvarts, 2025). What is considered emergent in such pedagogy is not formless spontaneity. Nor is what is structural a rigid form externally imposed upon activity. Structure arises within organised participation as certain cognitive pathways become more available, more shareable, and more portable. The educator's work, on this view, is neither to insert form into an otherwise empty learner nor simply to stand back and observe what unfolds. It is to participate in the cultivation of educational niches, arranging materials, preserving productive contrasts, varying conditions without collapsing them, pacing activity, joining attention, introducing symbolic means, and holding open a line of inquiry long enough for a cognitive pathway to deepen. Teaching thus becomes less a matter of transmitting finished content and more a matter of ecological choreography within a developmental field (Tamis-LeMonda, 2025; Vygotsky, 1978).

This is also why pedagogy cannot be separated cleanly from curriculum in the present account. Curriculum is not simply what is to be learned, later to be enacted through pedagogic means. It is already sedimented in the affordance structures, tools, symbolic resources, and culturally organised practices through which developmental cognitive pathways are made available. Pedagogy, correspondingly, is not a method applied to that content from outside. The two are reciprocally implicated in the cultivation of developmental niches. That implication can be seen clearly in the mathematical illustration, where relations of volume, capacity, more and less, remainder, and equivalence do not pre-exist as detached objects of instruction, but emerge through the organised participation of child, educator, and material arrangement.

Taken together, these implications amount to a modest but consequential reorientation. The present paper does not offer a complete theory of development, nor does it claim that every developmental phenomenon can be read straightforwardly through the same local configuration. What it does propose is a more adequate scale and vocabulary for developmental explanation: one that keeps continuity in relation, treats bodily and neural traces as materially significant consequences of participation, and allows pedagogy to be understood as the cultivation of affordance-rich cognitive pathways rather than the management of inner contents.

Conclusion

Past activity always has an influence upon present activity, so the popular use of the notion of the schema concept is not at all surprising. The difficulty has been that this clear temporal continuity has too often been conceptualised as if it required an inner structure that stores, organises, or regulates what later appears in action. The present article has argued for a very different reading. By returning to Piaget's distinction between operative schemes and figurative schemas and reconstructing that distinction in embodied-ecological terms, it has sought to relocate developmental order within lived child-environment relations rather than behind them (Piaget, 1952, 1971; Witherington, 2025).

On this reconstruction, developmental continuity is better understood through the SSAF, an episode scale achievement in which canalisation provides revisitable cognitive pathways of participation (Gottlieb, 1991; Waddington, 1957). Neural change matters here as a materially important consequence of repeated participation, but not as a hidden causal seat standing behind developmental formation (Fu & Zuo, 2011; Kolb & Gibb, 2011).

This reconstruction also clarifies why memory, transfer, and what is often described as self-regulation should be treated differently. Memory becomes the renewed availability of a canalised cognitive pathway rather than retrieval from an inner archive. Transfer becomes the reopening and extension of a cognitive pathway across analogous affordance relations rather than the movement of invariant contents from one context to another. Self-regulation also becomes less a matter of invoking an inner executive source than of describing the historical deepening of cognitive pathways through which pausing, revising, sustaining, and returning become increasingly available in organised participation (Piaget & Inhelder, 1973; Witherington, 2025).

The illustration from early mathematics shows that this argument is not confined to domains usually labelled sensorimotor or practical. Even where development is often assumed to concern abstract knowledge most

directly, the relevant unit remains the organised relation among cognitive pathway, world availability, and affordance. Mathematical structure does not arrive from outside embodied activity, nor does it wait fully formed within the child to be expressed. It emerges through the canalisation and reorganisation of cognitive pathways within culturally organised, materially structured participation (Shvarts, 2025).

For the author, the most important consequence of this reconstruction is pedagogical. If developmental structures take shape through the cultivation and reopening of such cognitive pathways, then teaching is better conceived not as the delivery of content into an inner architecture, but as the ecological arrangement and sustenance of conditions from which more differentiated structures of action and sense can emerge, be revisited, and become available for extension. In this respect, the argument supports what has here been called an emergent-structural pedagogy: a pedagogy concerned neither with imposing form from outside nor with celebrating undirected emergence, but with cultivating the affordance-rich niches within which developmental structure takes shape (Bril, 2025; Siraj-Blatchford, 2022; Tamis-LeMonda, 2025).

Statement of Ethics

No ethical approval was required for preparation of this theoretical manuscript. No human or animal subjects were involved.

Conflict of Interest Statement

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