In an integrated view of perception and action, learning involves all the senses, their interaction and cross-modality, rather than multi-modality alone. This can be referred to as synesthetic enactive perception, which forms the basis for more abstract, modality-free knowledge and a potential underpinning for innovative learning design. The authors explore this mode of learning in two case studies: The first focuses on a potential underpinning for innovative learning design. The authors which forms the basis for more abstract, modality-free knowledge and a potential underpinning for innovative learning design. The authors explore this mode of learning in two case studies: The first focuses on children in Montessori preschools and the second on MEDIATE, an interactive space designed for children on the autistic spectrum that offers a “whole-body” engagement with the world.

Over the past 5 years, the authors have been researching how people learn, interact and make sense of the world. We have drawn on insights from a range of theories and disciplines: affordances (from ecological psychology [1–3]), emergence (from complex adaptive systems [4,5]), embodied learning (from phenomenology [6] and haptics [7]), communities and networks [8] and networked learning [9]. A thread running through all this work is the idea that learning is more holistic and integrated across cognition, perception, context, affect and ontological development than previously acknowledged. Synesthetic ability and embodiment cut across all these areas and enable their configuration into a more coherent framework.

We have been inspired by several authors’ work on synesthesia. Ramachandran extrapolates from involuntary synesthesia (for instance, seeing numbers in color), which we will refer to as synesthetic perception, to a much broader notion of synesthetic ability [10]. Involuntary synesthetic perception clearly enriches many synesthetes’ lives and often inspires their creative imaginations [11–13]. However, it is the much broader and somewhat different notion of synesthetic ability (or emergent cross-modal abstraction) that concerns us here. We explore synesthetic ability further to shed light on our case studies on learning below.

SYNESTHESIA

Synesthesia was once seen as not much more than the product of some people’s quirky imaginations. That has changed completely. Ramachandran shows why synesthesia is now scientifically recognized as an involuntary, fixed and genuine sensory mode of perception based on anomalous cross-wiring, or cross-talk, between different senses and different sensory areas of the brain. We refer to this below as (involuntary) synesthetic perception. Ramachandran’s work builds on the hypothesis that synesthetic perception is based on individual genetic variation and that broader synesthetic ability (described in greater detail in the next section) is based on the more general evolutionary development of particular areas of the human brain [14].

Ramachandran distinguishes between two forms of synesthetic perception, depending on whether the genes are expressed lower down or higher up in the brain. If the gene is expressed in the fusiform gyrus, it causes synesthesia between senses (e.g. color and the shape of numbers). If the gene is expressed in the angular gyrus, it causes synesthesia between concepts (e.g. color and the concept of number, or “ordinality”). These variants of synesthetic perception are both involuntary and (although they can be temporarily extended by hallucinogenic drugs) fixed and cannot be learned or varied [15].

Synesthetic Ability

Ramachandran demonstrates, using Köhler’s boub/aiki experiment [16], that we all experience some involuntary (e.g. graphic object-to-sound) synesthetic perception. What is important for this paper is the more generalized notion of synesthetic ability, which Ramachandran says is an extrapolation of these inbuilt biases that we all have and a characteristic of
our evolutionary development. The bouba/kiki experiment shows that there is

a pre-existing translation between the visual appearance of the object . . . and the auditory representation in the auditory cortex. In other words there’s already a synesthetic cross-modal abstraction going on [emphasis added] . . . Now admittedly this is a very small bias, but that’s all you need in evolution to get it started and then you can start embellishing it [17].

He goes on to show that there are also pre-existing, built-in, cross-activation biases that map some shapes and sounds onto the motor maps in Broca’s area and similarly map movements between the hand area and the mouth area in the brain. (This was first described by Darwin.) Generalized cross-modal mapping such as this is widespread, and essential for the perception of all objects and movement in space (through perceptive-action [18] or enactive perception [19]), for language [20] and for the social basis of learning [21,22]). To quote Merleau-Ponty: “Synesthetic perception is the rule, and we are unaware of it only because scientific knowledge shifts the centre of gravity of experience” [23].

Ramachandran makes the case for a more flexible, emergent, complex and creative synesthetic ability to identify the patterns we perceive and to create new ones (over and above the involuntary and fixed associations of synesthetic perception). The type of synesthetic ability Ramachandran identifies is

not just a quirk in some people’s brains . . . if you compare us [with animals] there is a progressive enlargement of the . . . angular gyrus . . . strategically located at the crossroads between the parietal lobe (touch and proprioception), the temporal lobe (hearing), and the occipital lobe (vision); so it is strategically placed to allow a convergence of different sense modalities to create modality-free representations of things around you [emphasis added].

Once you develop this ability to engage in cross-modal abstraction, that structure in turn becomes an exaptation for other types of abstraction that [we] excel in, be it metaphor or any other type [24].

In other words, crucial parts of the brain that are involved in cross-mapping a range of sensory inputs not only give us our unique ability to perceive patterns (over and above associations) across the senses, but also allow us to use this ability and these basic synesthetic perceptual patterns to establish modality-free abstractions (e.g. metaphor, language, mathematics and abstract and creative thought), or patterns of patterns. This (meta-)synesthetic ability also enables us to integrate our responses to the environment across these senses, using more complex synesthetic modes of communication such as speech and other media.

**Embodied Cognition and Enactive Perception**

Many scientists and philosophers no longer consider mind and body separate from each other or from the environment but rather as mutually interactive and adaptive. This applies across the 17 or so senses that Paterson identifies [25] rather than the 5 discrete senses that we are still taught about at school.

Traditional studies of cognition-as-computation have given ground to studies of embodied cognition, including the ways in which the environment enables cognition, and the role of sensorimotor skills in cognitive development [26]. Most striking is the research by Cecilia Laschi [27], whose “morphological computing” approach to the design of robots assumes that intelligence resides not only in a central computing “brain” but also in the “body.” Unlike many robots that have hard humanoid shapes, her robots have soft, rubbery bodies that are able to move elegantly in water and respond flexibly to the environment, in a manner reminiscent of an octopus (Fig. 1). For Laschi, the octopus’s intelligence is in its body and its interaction with the environment. As Mullins explains: “With morphological computing, it’s not just the shape and substance of a body that’s important, it’s also the interaction with its environment that is crucial” [28].

**CASE STUDIES**

Two case studies, one on Montessori classrooms and another on MEDIATE, explore how these ideas are applied in practice. In both cases, the design implicitly includes substantial aspects of what (some years later) struck us as synesthetic ability.
Montessori

The Montessori classroom was created by Maria Montessori in the early 20th century as a setting in which young children might harness their enthusiasm to explore the environment and interact with it. Working first with young children with disabilities, these schools responded to the children’s need to interact physically with the world through embodied learning, using whatever facilities were available, and with minimal instruction. Montessori pupils explore patterns of physical coordination and then of material shape and form, before progressing to more abstract patterns. There is no traditional “instruction.” Intellectual development is grounded in direct experience—almost as if Montessori anticipated Gibson’s work on direct and enactive perception and meaning [30].

What is most radical about the Montessori classroom is the lack of instruction or “linguistic scaffolding.” Instead the child is invited to explore the senses directly: “The essential thing is for the task to arouse such an interest that it engages the child’s whole personality” [30]. This anticipates Gibson’s theory of affordances [31], which are neither “in” the child nor “in” the environment, but are rather the product of the interaction between the two [32]. Costall points out that Gibson “appeals, in effect, to a [level of] a-linguistic and ultimately a-cultural...human experience...Learning does not necessarily have to pass through the filters of linguistic coercion...or explicit instruction” [emphasis added] [33].

Examples: Substantial parts of Montessori mathematics—such as the Trinomial Cube, a 3D rendition of the trinomial theorem $(a + b + c)^3$ (Fig. 2)—are explored and mastered without any mathematical instruction. They are learned through a demonstration of the physical patterns and an invitation to explore them. The materials (blocks of wood) function as a tangible, synesthetic or cross-modal scaffolding for the complex patterns of the theorem.

Applying synesthetic ability to the Montessori environment raises interesting issues. Kindergarten pupils are invited to interact with materials, most often in silence. They are not given complicated instructions but rather invited to explore particular “sensorial materials” and, effectively, their cross-modal affordances. The patterns they explore in the Montessori classroom range from gross motor coordination (such as scrubbing a table) to (literally) expanding (the patterns of) algebraic equations in physical form.

The materials are carefully graded from synesthetically rich, 3D, haptic- and color-intensive materials to more abstract patterns. These materials are “strategically placed to allow a convergence of different sense modalities to create [an incremental series of abstractions, of increasingly] modality-free representations” [emphasis added]—to paraphrase Rama-chandran’s definition of extended synesthetic ability [34]. For instance, principles of numbers, such as base 10, are rendered as 3D colored models. As the child develops a stronger grasp of the concept, these materials are replaced with plain 3D models, followed by 2D colored and/or plain models, 1D models, text, numbers and finally mathematical script with built-in possibilities for recursive learning. The older child, expanding the expression $(a + b + c)^3$ in algebra some years later, often intuitively “walks back” to the trinomial cube, to its rich synesthetic patterns, to get a feel for the theorem, and for the way unpacking the cube literally expands the pattern of the expression. This stepwise progression from rich, cross-modal multi-sensorial experience, to patterns, to patterns of patterns, and then to modality-free patterns exploits synesthetic ability to the full.

MEDIATE

MEDIATE (Multisensory Environment Design for an Interface between Autistic and Typical Expressiveness) was a multisensory environment designed for “low-functioning” children on the autistic spectrum with little or no verbal skills. It was created in collaboration between five teams across Europe, involving designers, programmers and psychologists with a plethora of theoretical perspectives and drivers [35]. Psychologically, it focused on developing agency in an environment at once rich with sensory offerings and devoid of any social context or symbolic content. The environment (Color Plate C) was designed not to be therapeutic or to deliver a specific learning schedule but to engage children with autism so as to help them feel in control of their space, to enable them to play and to allow them to explore novel behavior and expressiveness. This process was at all times driven by the needs of the child in dialogue with the environment. The resulting capacity for dialogue with children on the autistic spectrum is a substantial achievement in its own right. It provides substantial pedagogic and social advances, whether it achieves additional therapeutic goals or not.

Fig. 2. Montessori trinomial cube. (Photo © Roy Williams)
It was also hoped that the children’s parents or caregivers could observe behavior and expressions, learn about sensory preferences and perhaps gain access to a world that is normally difficult for “neuro-typical” people (people without autism) to understand. Every individual with autism has unique idiosyncrasies, so it can be of great value for people close to a particular child to have a space to observe this form of sensory expression and communication.

Because the child was to control the interactive agenda and “dialogue” at all times, the environment had to be absolutely accessible and could not include any instruction or any social or cultural knowledge. As the premise was to allow novel and creative behavior and expression to emerge, the interfaces and interaction had to move beyond button pressing and predetermined interaction sequences. Our solution was to build a fairly large, almost round space that did not contain too many elements to fixate upon but enough to create an engaging experience and encourage exploration. The look and feel of the environment incorporated visual, audio and tactile interfaces and integrated a range of organic and haptically interesting materials and shapes, as well as space to move and run around freely.

The system was intended to be intelligent and adaptive. Pattern detection software was adapted to allow the system to build up unique, individual sensory profiles and identify novel, idiosyncratic behavior. The software, the so-called “brain” of the MEDIATE environment, produced varied responses based on whether the child was inert, fixating and repetitive, or creative and explorative. This pattern detection was useful, as it was not biased by human observers, but the step from pattern detection to meaning-making is still a substantial one and realistically requires human monitoring.

The challenge was to implement rules within the system that allowed as much self-organization and adaptability as possible. If the child displayed novel, exploratory behavior, the system increased the complexity of the interaction. The first entry into the environment was like walking into a sensory feedback loop; the surrounding environment became an amplification or extension of the child’s body. The interactive floor, for example, would produce footstep sounds akin to walking on crunchy leaves that corresponded directly to the weight and gait of the person. As this continued, the nature of the sound changed slightly into more complex, cross-modal responses—first a pitched crunch, later a singing voice. Similarly, the TuneFork (pictured on the right-hand wall in Color Plate C) would first amplify the sound a hand made by touching different textures (such as bark, cork, etc.); the amplification would relate directly to the material and the hand movement. This sound would then morph into more abstract sounds and produce cross-modal responses. For example, in a later stage of interaction, it was possible to tap the TuneFork to change the color of the screen. This cross-modal aspect was important in the design process.

Designing a holistic sensory experience in an artificially controlled, technology-mediated environment presents challenges, as the experience has to be reduced into sensory channels to create interfaces with sensors and outputs. Content that must be intuitively understood has to be specifically designed and mapped across sensory modalities. For example, the concept of verticality is generally accepted as a so-called image schema that can be realized across different sensory modalities. When the child raises her arm vertically in space, it would make sense to map this gesture to a response on the screen with, for example, a mirror silhouette raising an arm, but the environment might also respond arbitrarily, and cross-modally, by “raising” the volume or pitch of the sound “vertically,” as it were. Cross-modal mappings have to be specifically designed in an artificial environment, but this can allow the participant to discover or even create new mappings, in a kind of embodied, synesthetic orchestration that would be engaging for the participant.

**Examples:** Many children used the MEDIATE space. Among them were two children we will call Mr. Tunefork and Mr. Purple. Mr. Tunefork is a 5-year-old male without a diagnosis of autism. His visit was remarkable in that without any musical training he commandeered the sounds produced by the TuneFork—a rather unusual “instrument” in the traditional sense—to a high level of structured rhythm and pace. He moved up and down the bas-relief branch design (see Color Plate C), and although it seemed he was randomly touching and playing with the textures at first, he gradually began composing a fairly complex sound piece.

Mr. Purple is a 9-year-old male with a diagnosis of Asperger’s Syndrome who had experienced the environment at several stages of its development. At one point the interaction level moved to a greater complexity—and cross-modality—and he was able to change the color of the screens by tapping on the TuneFork. He proceeded to repeatedly select a purple hue. It might have gone unnoticed, but his mother observed it and believed that this might be an important form of sensory expression. The family proceeded to paint his bedroom in this purple hue and consequently experienced a much calmer child who was able to sleep through the night for the first time in many years.

**Comment:** Nearly all the children who experienced the MEDIATE environment were on the autistic spectrum and would be expected to find strange, dark spaces disorienting, if not frightening. None of them did. On the contrary, they intuitively found the space to be welcoming, inviting and safe for exploration and expression—quite dramatically so. Moreover, they found the space not a “thing” to interact with but rather a place to enter into, quite literally, in a deeply embodied (and possibly even a regressive) sense.

The choice of the pink color for the walls (see Color Plate C); the soft, responsive, and varied surfaces (from the floors to the walls); the soft lighting; and the gentle, inviting and challenging “brain” all contributed to the children’s positive response to the environment. Within this space they found comfort at a rich, encompassing, literally “deeply synesthetic” and unmediated level, in what could perhaps be called Gibson’s dream scenario for “direct enactive perception.”
**DISCUSSION**

Synesthetic ability is not just an interesting curiosity; it provides us with the neurological basis for enactive, embodied, cross-modal learning and behavior [16]. The case studies on the Montessori classroom and MEDIATE demonstrate long-established as well as recent, innovative examples of the incorporation of synesthetic ability in learning design.

The Montessori preschool shows how synesthetic ability can be rendered, embodied and curated in learning materials. The child is provided with learning tasks that incrementally grow more complicated in the materials and also in small, incrementally more sophisticated abstractions, guiding students from rich, synesthetic cross-modality learning to the most abstract, modality-free texts. It is almost as if Montessori set out to enlist the angular gyrus as a proxy teaching assistant. Clearly such rich integration of cross-modality is more applicable to certain kinds of learners and stages of development (such as early childhood development) than others, but the value lies only partly in direct application. It also lies in a more general, creative awareness of the synesthetic, cross-modal foundations of learning, in the literal and metaphorical sense.

For instance, one of the authors [Williams] had to teach 10-year-old children who had little background or basic competence in mathematics to count in different number bases. The children were skipping competitively in the playground at the time, so the author got them to skip in the classroom for two days, counting in different number bases. They soon had no problem counting in any number base thrown at them, even while they were skipping. Similarly, Quinn's research into young people on the margins of education [37] describes learners who floundered in the sensorially and synesthetically impoverished abstract setting of text-based schooling, which assumes that the transition from rich embodied cross-modal experience to written text is natural, comfortable and self-evident for all students. Quinn's learners also thrived as soon as they were put (back) into rich synesthetic settings—in their case, in a farm-based school. They seemed to have been yearning for the "reinstatement of all their other (16 or so) senses" [38]. They were potentially quite capable of engaging with written text, given the right guidance and time, but they experienced the "cold turkey" approach of schooling and the "shock of the text" as intolerable and disorienting.

MEDIATE, on the other hand, shows how it is possible to embody synesthetic ability and enactive meaning in an interactive space that "inorporates" the learner in an immersive, simulated synesthetic presence, built around its own virtual angular gyrus, so to speak. This simulated presence is not "external" to the learner; the learner literally enters into it, by going into a womb-like space, and interacting from the "inside."

**Comfort and Agency**

MEDIATE's rich, encompassing, deeply synesthetic, unmediated zone provides a "home" for the development of autonomous agency and the expression of a creative, engaging, embodied self in dialogue with another. Happé, a member of the MEDIATE team, formulated it thus in a 2002 personal communication:

Ordinary young children . . . have the sense of agency [early on] . . . in the social world. A very young infant from four months can smile at a parent, the parent smiles back, they immediately have a sense of acting on the world . . . and that's long before they can control their motor movements and affect the world in that way . . . . Children with autism, partly because of their social problems, don't have such an experience of control over the world . . . . The world for them is typically chaotic and unpredictable. So the point of MEDIATE . . . is to give the child an experience of being utterly in control, where their world is suddenly no longer chaotic.

The MEDIATE "brain" (or mind) satisfies some of the criteria for other (cognitive) minds (as in Theory of Mind research) in which the participant has to best-guess what is going on in the other mind with which they are interacting. In MEDIATE the dialogue was based on the contingency (or randomized variation) built into the program, which had to be adaptive and finely tuned to achieve a Goldilocks level of contingency (not too much, not too little) and invite and guide the participants out of repetitive loops and into a creative, expressive space.

However, the achievement of a fundamental, intuitive level of comfort-in-a-strange-place introduces quite different dynamics to those involved in a "cognivist" Theory of Mind interaction. Experience in MEDIATE seems to overlap with what Turkle [39] describes as emotional engagement and projection with robots, in which people not only develop affection for what we might call “ET-bots,” but also experience the ET-bots as reciprocating emotional engagement and “loving” them back. We might call this theory of heart. This raises a further issue: Is MEDIATE just an example of a combined Theory of Mind and Heart? Or is there something more fundamental and integrative at stake, which we could call a Theory of Synesthetic Mind—a dialogue that deliberately and sensitively accentuates cross-modality in its responses? We might learn something from this that would be applicable to neuro-typical children too, just as Montessori’s early work with disabled children provided the foundations for early learning for all children.

**CONCLUSION**

The two case studies share a radical notion of synesthetic ability, starting with cross-modality and extrapolating into the modality-free abstractions of language and knowledge implicit in design and explicit in realization. Both provide a starting point for engagement that is embodied and synesthetic. In MEDIATE, embodiment is taken to a new level: the immersive embodiment of body/mind. The two are embedded so deeply that we might need a new term: “embodiedmind.” In both cases the core engagement is embodied, material, direct and intuitive; in both cases the standard linguistic and cognitive scaffolding is designed out—as far as possible—to enable what Gibson aspired to: direct enactive
perception and meaning [40] that exploits layers of cross-modality to the full in “synesthetic scaffolding” and even in “synesthetic orchestration,” leading to modality-free expression in abstract patterns.

Although both are radical in their approaches and solutions, the two cases differ in the extent to which they engage with the transcription and abstraction of patterns beyond rich synesthetic engagement. MEDIATE focuses on putting the child in charge within a synesthetic experience inside a (virtually) simulated embodiedmind, which generates emergent sensory and cross-modal traces—potential transcriptions, text and even transformations that can be taken further, as in the case of Mr. Purple and his experience with the color purple.

The Montessori example shares these concerns for the primacy of ontological development, agency and self as a site for engagement and dialogue with the world. In the Montessori classroom, as children establish agency, they move on to other modes of interaction and knowledge. Montessori materials are designed to extend and engage the child in emergent stages of learning, building on a foundation of rich synesthetic cross-modality and moving on gradually to modality-free abstraction.

The value of the framework of embodied synesthetic ability lies in the fundamental nature of enactive perception and enactive meaning and the role it can play in various forms—from the “immersive” synesthesia of an environment like MEDIATE to the very different Montessori environment, in which engagement ranges from the rich synesthetic to the abstract (and back to the rich synesthetic in re-engagement and in recursion). Synesthetic ability can potentially enrich learning by providing affordances for perceiving and engaging intuitively with the world, as well as the crucial capability to explore, express and engage in dialogue with the internally motivated self, building up comfort, agency and capability.

Implications for Future Research

Synesthesia foregrounds two modes of active engagement with the world: cross-modal and modality-free. This is based on the progression and extrapolation from involuntary synesthetic perception across senses to involuntary synesthetic perception across senses and concepts, to broader synesthetic ability, which identifies and creates completely new, modality-free abstractions.

This raises interesting questions about how largely intuitive engagement with the material, trinomial cube can provide rich, cross-modal forms of engagement for what is also, in the algebra itself, modality-free mathematical knowledge.

This is contrasted against the (Peircean) symbolic engagement of the abstract modality-free written text, which has its own power in its ability to articulate totally new knowledge, through the arbitrary and conventional nature of language and semiotics. It is also contrasted against what might be called the “intuitive-aesthetic” engagement of art, which is paradoxically more abstract and more intuitive than the symbolic, for example in the work of artists like Brancusi (Fig. 3).
This is in a sense a “pure” or “open” form. Your first response is intuitive, and an explanation might diminish your appreciation rather than enhance it, despite the rich inter-textuality. Brancusi might almost have invented the term intuitive-aesthetic. He writes that “there are idiots who define my work as abstract; yet what they call abstract is what is most realistic. What is real is not the appearance, but the idea, the essence of things” [41].

Pure mathematics can function in a similar mode, leading to the discovery of mathematical patterns that capture relationships in the abstract. These elegant and beautiful patterns, e.g. Mandelbrot fractals, often relate to phenomena that may be scientifically described only many years later [42].

What is important to recognize is that all three modes—intuitive, symbolic and intuitive-aesthetic—provide rich, powerful modes of engagement situated in or derived from the rich spectrum of synesthetic ability that we have explored here and that there is work to be done in leading learners from the one stage to another.

References and Notes

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COLOR PLATE C: SYNESTHESIA

The MEDIATE Environment for children on the autistic spectrum.
(Photo: Simone Gumtau) See article in this issue by Roy Williams et al.