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Enhance Learning Environments Using Knowledge Flow: A Living Systems, Neuroscience-based Model

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Abstract

This study introduces the Knowledge Flow framework, a living systems, neuroscience-based learning model designed to enhance engagement and academic performance in large university courses. Moving beyond linear learning models that mirror traditional "banking" approaches to education, this framework reconceptualises learning as energy flow within interconnected systems, prioritising wonder and belonging as foundational elements rather than educational luxuries. The framework comprises seven Knowledge Catalysts that create structural foundations and four Knowledge Currents that describe resultant dynamic energy flow, with the torus introduced as a three-dimensional model for visualising non-linear learning processes. Foundational catalysts Meet Me (scaffolding) and See Me (belonging) are positioned as essential prerequisites for effective learning environments. Implementation in a large introductory neuroscience course (n=300+ students) demonstrated significant improvements in student performance compared to traditional lecture formats (82% vs 79%, p<0.0001). The study provides practical implementation resources, including an engagement rubric for real-time assessment and guidelines for undergraduate teaching assistant integration. By reframing Maslow's hierarchy to position self-actualisation as a basic safety need rather than an aspirational goal, this approach offers educators a systematic method for transforming large courses into inclusive learning environments that support diverse student populations. The framework addresses educational inequality while prioritising student well-being and natural curiosity as essential components of effective pedagogy.

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Practitioner Notes

1. The novel Knowledge Flow framework applies living systems theory and neuroscience principles to education, providing Knowledge Catalysts for transformative learning to occur within a living system.
2. A torus model mirrors neural network functioning, where learning flows dynamically through feedback loops rather than linearly, allowing knowledge to circulate and regenerate through interconnections.
3. Implementation combining asynchronous lectures with in-person small-group activities increased exam scores significantly (p<0.0001) while fostering community, engagement, and TA pedagogical training.
4. This approach reconceptualises Maslow's hierarchy by positioning wonder and self-actualisation as foundational human safety needs rather than as higher aspirations, making them essential for learning.

Keywords

Active learning, Scaffolding, Inclusive teaching, Neuroscience education, Self-actualisation

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Introduction

Universities currently struggle with teaching challenges in introductory courses, which are traditionally taught in a lecture-heavy format in large auditorium-style classrooms to accommodate student demand. As higher education institutions worldwide strive to widen participation and create more equitable learning environments, redesigning large introductory courses becomes an essential strategy for fostering greater inclusion. The realities of student and economic demand for courses must be balanced with more pedagogically desirable activities, and this tension has spurred creative course design approaches using more active learning strategies (Michael, 2006; Persky & Pollack, 2010). Though discussion and concern about large class size have persisted for decades, lectures remain a well-accepted teaching modality, representing approximately 75% of current student course experience at one medium-sized urban US university (Johnson & Coulter-Kern, 2024). Creating opportunities for interaction in larger classes is therefore a crucial first step toward developing more student-centred classrooms (States et al., 2024), leading to lecture supplements such as integrated student response clicker questions (Wakefield & Tyler, 2023) to gauge real-time feedback or additional discussion sections for deeper engagement (Persky & Pollack, 2010).

Within my large, public research, university setting, I observed two instructional challenges regularly present in introductory classes: 1) low student active participation in lecture-heavy courses, with student interactions limited to questions in large lecture halls or within TA discussion sessions, resulting in 2) a decreased sense of belonging and inclusion in some students, particularly those from historically under-represented groups. As a partial solution, these large lecture courses were reimagined to be more active and inclusive in nature using a hybrid/blended model that combined online instruction with in-person learning. Previous work shows that when combined with online lectures, an active classroom approach is viewed favourably by students in large university courses with no drop in learning outcomes (Baepler et al., 2014), and this type of self-regulated learning may be preferred by nontraditional students (Sutherland et al., 2024). However, these incremental modifications, while useful, fail to address a deeper problem; traditional educational approaches systematically eliminate the conditions under which transformative learning occurs. When students describe their most meaningful educational experiences, they invariably reference moments of wonder, discovery, and personal connection to ideas. These moments emerge when learners feel simultaneously challenged and supported, and they can explore ideas freely while feeling genuinely seen and valued. Yet our current systems, designed for efficiency and standardisation, create environments antithetical to wonder.

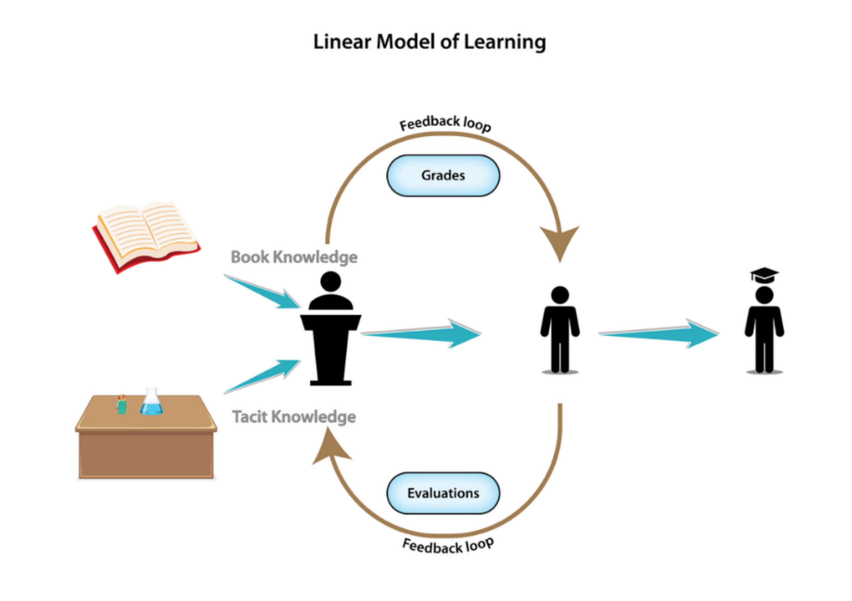
This disconnect becomes particularly problematic when we consider Maslow's hierarchy of human needs. While conventional interpretations suggest self-actualisation comes only after all basic safety needs are met, I propose that wonder, creativity, and self-discovery may actually be foundational requirements for psychological safety, particularly in educational settings where identity and belonging are constantly negotiated. Like applying a Band-Aid to a haemorrhaging wound, modest reforms cannot address the fundamental crisis: our educational systems are bleeding away the natural curiosity and joy that should fuel learning. As a neuroscientist, this paper outlines my development of a novel approach to consolidate many types of evidence-based active learning techniques in a holistic way. This work introduces the Knowledge Catalysts framework as seven interconnected elements that create conditions for deep learning while prioritising inclusion and belonging. The framework challenges linear models of education by proposing a torus-shaped model of knowledge flow that mirrors how neural networks actually function. Through a pilot implementation in a 300-student neuroscience course, this study examines how reconceptualising learning as an organic, non-linear process can significantly improve student performance, engagement, and sense of belonging. The paper concludes by reframing Maslow's hierarchy to position self-actualisation and joy in learning as foundational safety needs rather than aspirational goals, arguing that wonder and intrinsic motivation are not educational luxuries but essential prerequisites for creating truly inclusive learning environments.

Theoretical Framework

Moving Beyond Linear Learning Models

In my experience, traditional educational approaches typically follow a linear model of learning (Figure 1), where information flows in one direction from instructor to student and assignments build off the previous modules, with assessment/evaluations serving as feedback mechanisms. Previously described as the "banking model of education" (Freire, 1978), where the "sage on the stage" (King, 1993) aims knowledge transmission at the student, this model makes assumptions about learning as a linear process, and in so doing, it fails to capture the complexity of how learning actually occurs in the brain.

Figure 1
The Linear Model of Learning



Note. Conventional pedagogical knowledge conceptualises knowledge as flowing unidirectionally from expert (behind lectern) to novice student with periodic assessment checkpoints (Freire, 1978; King, 1993). Grades evaluate content mastery and give feedback to the student, while course evaluations (if applicable) provide the instructor with feedback. Once the loops are completed successfully, the student graduates (far right).

From a pedagogical perspective, learning can be defined as "an enduring change in behaviour or in the capacity to behave in a given fashion which results from practice or other forms of experience" (Schunk, 1991, p. 4). This definition focuses on behaviour, or outcome. Traditional approaches to learning (including behaviourism, cognitivism, constructivism, connectivism, and humanistic learning theory) each describe different aspects of how learning occurs (Ertmer & Newby, 2013; Gandhi & Mukherji, 2024; Giannoukos, 2024). However, in practice, instructional techniques use elements of many overlapping learning theories simultaneously in active learning (Stewart, 2021). My personal experiences with active learning techniques have shown that each approach has strengths and weaknesses, so they need to be implemented simultaneously, which can be confusing to the instructor. When earnestly engaged in teaching university courses, I quickly found that a working classroom system was somehow more than the sum of its parts. A more holistic approach was needed, one that could be grown, not just built; one that could be felt, not just evaluated.

This paper presents a novel approach to addressing these challenges through a living system, neuroscience-based learning model. The model introduces seven Knowledge Catalysts as a user-friendly framework that instructors can use to enhance student experience, joy in learning, and learner retention. When learning experiences are built with these catalysts, they allow for four essential Knowledge Currents to arise within the classroom. This framework uses both structure and function to design a system. Importantly, the model prioritises two foundational catalysts—Meet Me (providing flexible, scaffolded structure) and See Me (fostering belonging and recognition)—as essential prerequisites for creating truly inclusive learning environments where effective learning can occur. This paper addresses the following questions:

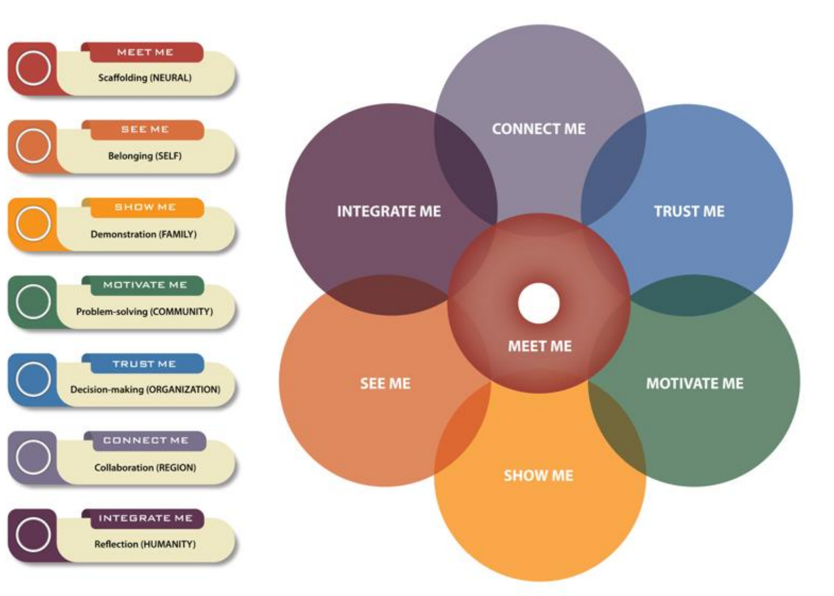
1. How can knowledge of living systems be used to design an inclusive educational experience that supports learners of all types?
2. How can neuroscience inform our classroom design practices?
3. How can large introductory courses be redesigned to increase active participation and sense of belonging for all students?
4. How can the Knowledge Flow framework be implemented to promote engaging and effective learning environments in large university courses?
5. What impact does a pilot Knowledge Flow hybrid classroom implementation combining asynchronous online lectures with in-person active learning sessions have on student performance and engagement compared to traditional lecture formats?

Literature Review

Knowledge Catalysts: A Framework for Inclusive Teaching

The Knowledge Catalysts framework (original to this study) systematises active learning methods into a cohesive structure designed to address both individual learner needs and the characteristics of the classroom as a living system (Figure 2).

Figure 2
The Seven Knowledge Catalysts



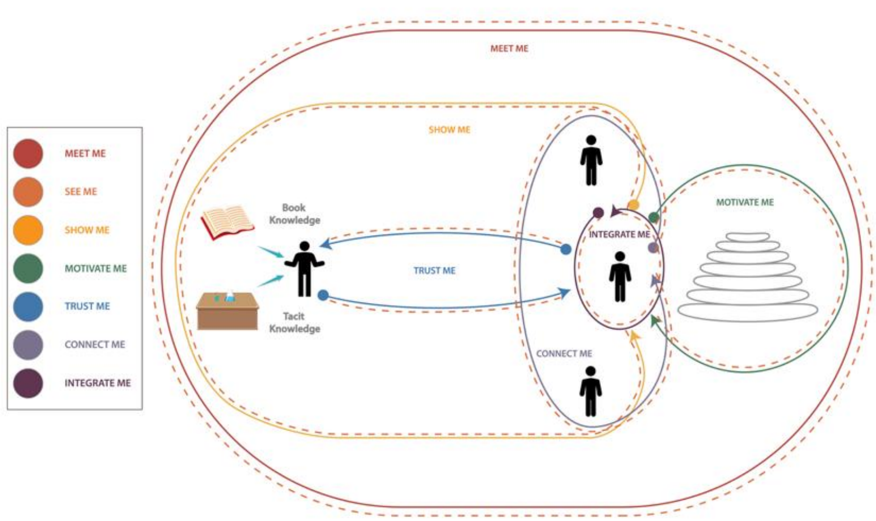
Note. The integrated framework aligns with multiple perspectives of scale to create an holistic learning approach containing seven interconnected dimensions of student engagement: Meet Me (Scaffolding), See Me (Belonging), Show Me (Demonstrating), Motivate Me (Problem-solving), Trust Me (Decision-making), Connect Me (Collaboration), and Integrate Me (Reflection). The Knowledge Catalysts support multiple facets of the educational experience simultaneously to enhance student experience through mutual reinforcement. Critically, I argue that the first two catalysts—Meet Me and See Me—must serve as the foundation for any inclusive teaching approach. Without appropriate scaffolding (Meet Me) and a sense of belonging (See Me), students often struggle to engage with even the most well-designed active learning environments. These foundational catalysts create the necessary conditions for all students to participate fully in the learning process, addressing barriers that disproportionately affect under-represented and non-traditional students.

The framework is built into the curriculum, and consists of seven key components, each designed to address different aspects of the learning process and corresponding to different levels of scale in living systems. First, meet me (neural level) establishes scaffolding for course design that is student-centred, offering a competency spiral that provides structure while gradually releasing responsibility to the learner (Puntambekar & Hubscher, 2005; Reiser, 2004). Second, see me (self-level) focuses on understanding students on a personal level, beyond their intellectual capacities, emphasising inclusion, differentiation, and Vygotsky's zone of proximal development (Gauvain, 2008). Third, show me (family level) models desired behaviours and engages in inquiry-based activities alongside students, facilitating a hands-on learning environment through demonstration and co-teaching (Merrill, 2002). Fourth, motivate me (community level) fosters intrinsic motivation by connecting learning to students' personal interests and real-world problem-solving by allowing application of new knowledge, as connecting instructional materials to authentic tasks significantly improves learning outcomes (Zachrich et al., 2024). Fifth, trust me (organisation level) builds trust by allowing students to explore and understand their own learning processes, activating prior knowledge and providing decision-making opportunities to enhance ownership (Cullen & Oppenheimer, 2024; Stefanou et al., 2004). Sixth, connect me (region level) emphasises the importance of connection and collaboration among students and between students and instructors, creating interactive feedback loops and collective knowledge building (Siemens, 2004). Seventh, integrate me (humanity level) incorporates time for reflection and integration of learning through discussion or reflection, recognising that self-awareness is crucial for deep learning (Hutchinson & Allen, 1997; Linn, 2024).

A Living Systems Approach to Learning

Our higher education structure currently teaches students in ways contrary to how neuroscience tells us the brain learns. Instead, we navigate through an institution and instructor-centred system. When developing this new model, I leaned heavily on the definition of learning from a Hebbian neuroscience perspective, meaning "the process by which new information is acquired by the nervous system... explained by coordinated activity of a presynaptic terminal and a postsynaptic neuron to strengthen the synaptic connections between them" (Purves et al., 2001, pp.665, 531). This definition of learning focuses on the process that yields a functional change in anatomy (and therefore behaviour). The brain itself is non-linear—it functions as an interconnected network where learning involves the strengthening of synaptic network connections through use and experience.

Figure 3
The Knowledge Catalysts Framework in the Classroom



Viewed from a more living system approach, learning occurs within interconnected social and cognitive environments. Traditional knowledge transfer mechanisms (book knowledge and tacit knowledge) interact within a complex ecosystem of student-centred engagement dimensions. The nested structure shows Meet Me as the outermost fundamental container, with Show Me, Motivate Me, Trust Me, Connect Me, and Integrate Me as intermediate core interactive ways to enhance learning. See Me is depicted as orange dashes that enhance all other processes, as inclusion is a goal of the system.

When describing a system, a living systems approach pays careful attention to the flow of energy and resources and to the patterns of interactions between nodes, rather than just focusing on the structure (Meadows, 2008). Complex living systems have other characteristics that are not always evident in classrooms due to the constraints we place on their functioning. These include the ability to maintain homeostasis, to self-correct through feedback loops, to self-organise, to evolve, and even to attain a level of consciousness (Meadows, 1999). By controlling the flow of energy in the classroom too rigidly, we bypass the very strengths of the system we hold—the human needs to create, freely engage, and find purpose.

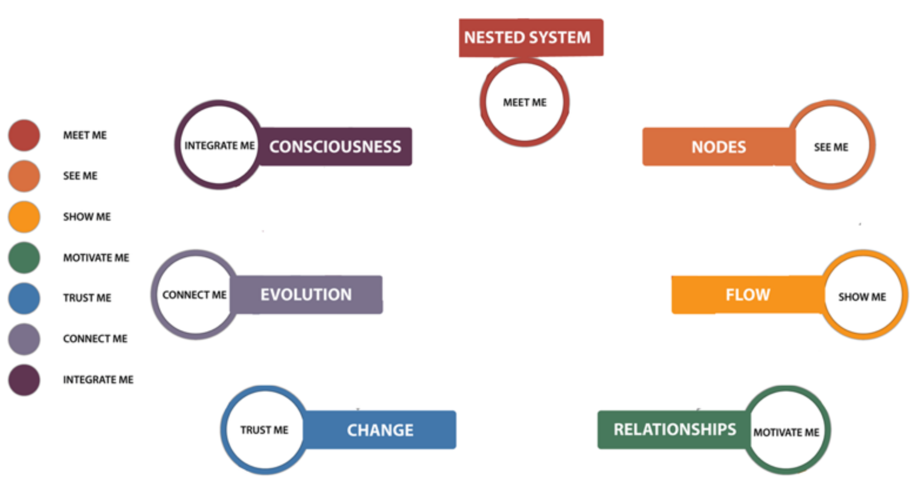
This paper supports a shift away from linear learning models toward a living systems approach that better aligns with how the brain actually learns and develops (Caine & Caine, 1991; Goswami, 2006; Immordino-Yang & Damasio, 2007; Kandel, 2001). Living systems are characterised by: 1) nodes (or entities), 2) interconnections between the nodes, and 3) a function or purpose (Bertalanffy, 1973; Miller, 1972). In educational contexts, the individual learner is a complex living system, as is the classroom. The classroom is composed of students, teachers, resources, and the environment, which are all nodes, and the relationships and interactions between them form the interconnections. Nodes and interconnections can create energy flow in a living system in the context of a classroom (Figure 3). We begin to see how knowledge flows through these interconnections like energy, creating a dynamic learning environment to serve a purpose, which is to promote learning and development.

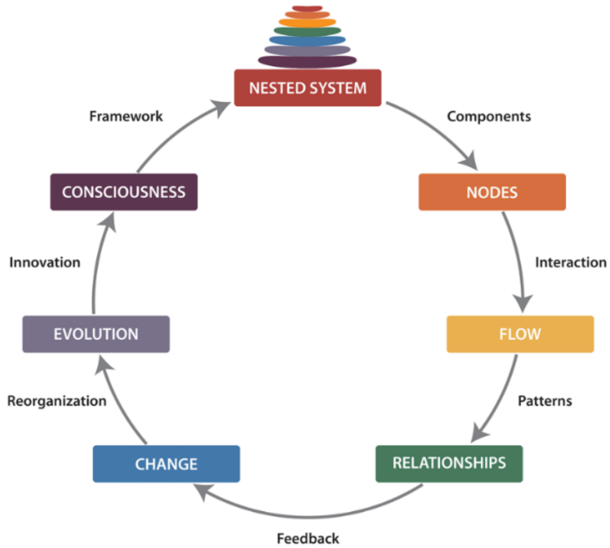
Beyond Linear Flow: The Torus Model of Learning Based on Neuroscience

The traditional linear model of learning fails to capture the dynamic, interconnected nature of how knowledge actually flows in a living system. Rather than viewing learning as a straight line from instructor to student, a more accurate model is the torus (introduced here for the first time): a doughnut-shaped 3D shape that allows for continuous flow, feedback, and integration (Figure 4).

Figure 4

The Seven Knowledge Catalysts Build a Living Systems Model of Learning





The components of a living system cycle together (Birney, 2021; Meadows, 1999) and are reconceptualised as the Knowledge Catalysts. Panel A shows conceptual mapping between Knowledge Catalysts (Meet Me, See Me, Show Me, etc.) and their corresponding living system elements (Nested System, Nodes, Flow, etc.) in a cyclical process. Panel B shows how each catalyst builds upon the previous one, creating a continuous feedback loop that enables emergent learning. The pyramid structure (top of Panel B) symbolises how these connected catalysts collectively construct a nested system.

In living systems theory, the torus is used to describe nested systems that are highly dependent on feedback mechanisms. A torus-shaped model also has multiple applications in neuroscience, particularly in describing dynamic firing patterns between populations of nerve cells. Toroidal flow patterns transmit and process complex signals in the inner ear (Ju et al., 2018), neural network activity of grid cells display a torus structure when organising information in mental maps (Gardner et al., 2022), and the torus is associated with higher order brain functions (Tozzi & Peters, 2016), including perhaps consciousness (Meijer & Geesink, 2017). This 3D doughnut shape exists not when a single neuron fires, but during connectivity *between* neurons.

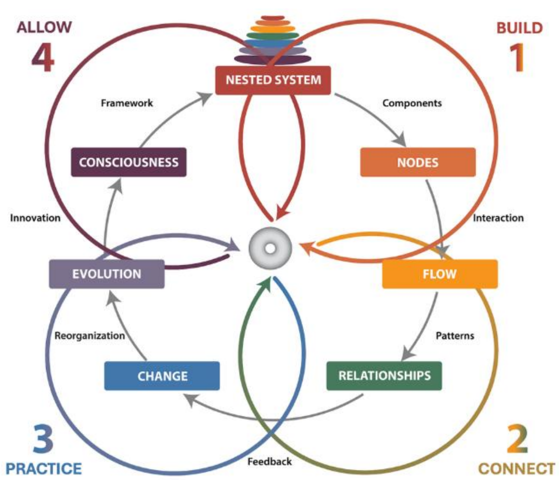
The knowledge journey can also exhibit this torus structure, where learning spirals between stable and unstable states rather than proceeding in a linear fashion. Just as normal neurodevelopment happens in uneven spurts (National Research Council and Institute of Medicine Committee on Integrating the Science of Early Childhood Development, 2000), a learner does not walk upward on one stable step at a time; rather, instability is a natural part of the system. In a classroom setting, the instructor may control the parameters for learning (the scaffolding; x-axis) and allow the flow (y-axis), but the way the system responds can emerge organically and uniquely, and that is what forms the 3D structure of the torus (z-axis). This mirrors how effective learning environments balance structured scaffolding with space for creative exploration and productive struggle. The overall shape can adapt while preserving its fundamental flow pattern, just as effective learning environments maintain core principles while adapting to the needs of diverse learners.

The Four Knowledge Currents: Energy Flow in Learning Systems

Like energy, knowledge is a natural circuit that does not flow solely in one direction but is most dynamic and accessible when completing a loop. This loop structure allows knowledge flow to regenerate through use rather than trickling out. Whereas the Knowledge Catalysts are structural elements, the Knowledge Currents are functions that emerge from the system once all Knowledge Catalysts are present (Figure 5). The torus model of learning develops through four key Knowledge Currents. The first Knowledge Current is Build (Nested System, Nodes, Flow), or the nodes of a living system make a circle when all are present. Just as neurons must be properly positioned in a cortical column before mature signalling can begin, the essential elements of a learning environment must be assembled first. The second Knowledge Current is Connect (Flow, Relationships, Change), which once connected, flow informs a complex living system that can function independently. Like neuronal pathways that strengthen with use, learning connections become more robust as knowledge flows between elements of the system. The third Knowledge Current is Practice (Relationships, Change, Evolution); as the system is used, the ease of flow through the circle improves. This mirrors how neural circuits become more efficient with repeated activation, requiring less energy for the same output. The final Knowledge Current is Allow (Evolution, Consciousness, Nested System); as flow accelerates, it can transform from a 2D circle to a 3D torus model of learning. This transformation cannot occur unless the system has freedom to self-organise. Similarly, learners need both structure and freedom to develop higher-order thinking.

Figure 5

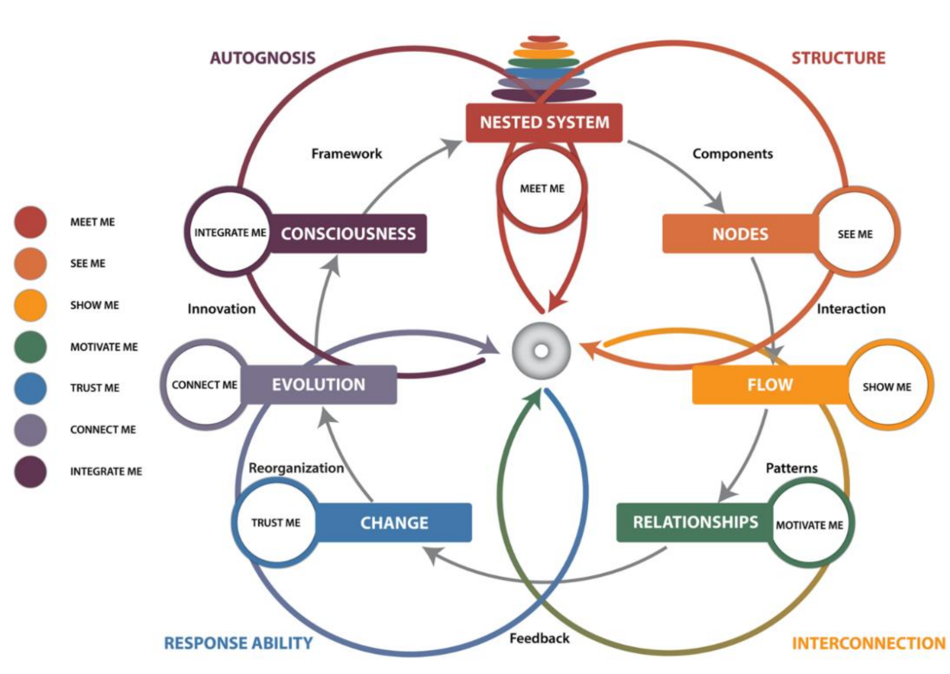
Knowledge Currents within a Learning Living System



Knowledge Current 1 (BUILD) connects nodes and flow elements through the components and interactions to support basic learning. Knowledge Current 2 (CONNECT) links flow and relationships elements through patterns and feedback to allow knowledge to move between different parts of the system. Knowledge Current 3 (PRACTICE) connects change and evolution elements through feedback and reorganisation so the system can adapt and transform in response to new information. Knowledge Current 4 (ALLOW) arises from evolution and consciousness elements through innovation and new frameworks to support self-knowledge and awareness, which then informs the nested systems structure.

Most knowledge dissemination models address Currents 1 and 2 and thus include only the first few steps in a living system (nodes, flow, relationships). Unfortunately, this retains a linear model that cuts off knowledge loops and impedes organic flow. By reconceptualising knowledge as energy flowing through an interconnected system, we can design learning environments that support more natural knowledge circulation. Imagine knowledge flow as water instead of information. Traditional education approaches dam up holes to prevent leakage, overfill cups of brains, and ask students to sit still so they don't spill a drop. Education has become like a bucket pouring, rather than allowing knowledge to flow naturally through an interconnected system. A living systems learning experience designed using the seven Knowledge Catalysts for structure will result in the four Knowledge Currents as emergent properties instead (Figure 6).

Figure 6
Structure/Function Relationships in Knowledge Flow



The seven Knowledge Catalysts are specifically connected to the four Knowledge Currents to ensure ease of knowledge flow in the living system model. The living system structure (Nested System, Nodes, Flow, Relationships, Change, Evolution, and Consciousness) are each associated with a corresponding Knowledge Catalyst (Meet Me, See Me, Show Me, Motivate Me, Trust Me, Connect Me, and Integrate Me) to form a comprehensive learning ecosystem, turning a complex model into understandable implementation tools for classroom use. The structural Knowledge Catalysts create the framework, while Knowledge Currents (BUILD [Structure], CONNECT [Interconnection], PRACTICE [Response Ability], ALLOW [Autognosis]) flow through the system. At the centre, the torus emerges, representing the focal point where all catalysts and currents converge, facilitating self-actualisation through dynamic exchange with self and the outside world.

Method

Bounded Case: Pilot Course Implementation

This study employed a case study methodology (Merriam, 1998) using within-case comparative analysis to examine the effectiveness of the Knowledge Flow technique. The Knowledge Flow framework was implemented as a course redesign in the Survey of the Neural Basis of Behaviour course (PSYC2200), a core requirement class for Psychology and Cognitive Science majors in the Systems/Behavioural Neuroscience area with no prerequisites. This course was previously taught as a twice weekly lecture-only course with multiple choice assessments to approximately 300 students at a large R1 research institution where in 2021, the undergraduate student body was 60% female, 55% White, 16% Asian, 7% Black, 7% Hispanic, 5% multiracial, and 10% non-resident/unknown, with 13% first generation college students (UVA College and Graduate School of Arts and Sciences, 2021).

The new approach incorporated a hybrid model with Knowledge Flow elements designed to enhance inclusion and engagement through a non-linear model. Instructor-centred elements of behaviourism (multiple-choice exams requiring memorisation) and cognitivism (lectures and visual tools) were also maintained from the original course structure, but the new course structure incorporated student-centred elements drawing from constructivism (emphasising discovery and peer review (Razumnikova & Bakaev, 2022), and connectivism (by collaborative knowledge sharing and self-driven learning (Gandhi & Mukherji, 2024) including online lectures, weekly in-person sessions, belonging and engagement focus, and a reimagining of the role of teaching assistants.

The lecture content was flipped so students engaged with recorded videos asynchronously. Two 45-minute lectures were released to students in a timed format each week. The model's hybrid approach allows students to engage with content in ways that accommodate their individual circumstances without sacrificing the benefits of in-person community. Students attended class for 75 minutes once each week for hands-on activity sessions. Students were placed in groups of nine at circular tables, maintaining the same seats and groupings throughout the semester to foster community and belonging. The first class began with an explicit focus on belonging, where students were overtly told "You belong in this course." This message is particularly important for first-generation students and those from underrepresented groups who may question their place in higher education. Each class started with a <5-minute small group activity to build rapport. Students wore nametags each day, contributed to assignments with individual colour markers to ensure representation of each person's effort, and collaborative peer teaching of concepts was strongly encouraged. A key innovation was the introduction of Undergraduate Teaching Assistants (UTAs), who facilitated all active learning sessions and graded student engagement in real-time for two tables (18 students each) using iPads. The use of an Engagement Grading Rubric during class allowed every enrolled student to have a 20-point individual score for each active learning session on five criteria, including Preparedness, Activity Contribution, Lifelong

Learning Practices, Group Climate, and Knowledge Resources (Table 1). A new 1-credit "Undergraduate Teaching Experience" course was established for the UTAs to train them how to teach and to provide pedagogical structure/support for class sessions, and to help troubleshoot classroom activities. The course met weekly to prepare the TAs to assist with the upcoming session and to offer discussion and reflection opportunities (debrief/prep). In addition, UTAs completed a mid- and end-of-semester reflection assignments and a final portfolio assignment on skills transfer to their intended career path. Graduate Teaching Assistants (GTAs) took on an additional role of helping train UTAs. All TAs received training in inclusive teaching practices and recognising barriers that might affect students from diverse backgrounds.

Table 1

Engagement Rubric for In-Person Session Contributions

Criteria	**Excellent** (4 pts)	**Fair** (2 pts)	**Poor/Missing** (0 pts)
Preparedness	Student arrived on time for class today; AND Student was prepared for class/had engaged with all assigned materials	Student was no more than 10 mins late; OR Student was marginally prepared for class/may not have engaged with all assigned materials	Student was more than 10 mins late for class today; OR Student was unprepared for class/had not engaged with all assigned materials
Activity Contribution	Student actively participated in group work/discussions and fully engaged with the activities; AND Student contributions were meaningful	Student only partially participated in group workload/discussions or was marginally engaged; OR Student contributions were very basic	Student did not actively participate in group discussions or workload; AND Student was not engaged with the activities
Lifelong Learning Practices	Student exhibited openness to learn through the activity; AND Student made obvious connections between their previous learning/life experience and the activities	Student had a neutral mindset toward learning through the activities; OR Student made few to no connections between their previous learning/life experience and the activities	Student exhibited evidence of closed mindset towards learning in the activities; AND Student made no obvious connections between their previous learning/life experience and the activities
Group Climate	Student contributed to maintaining a positive group climate; AND Student facilitated team working together to effectively complete the activity; AND student helped set up and clean up shared space	Student had neutral contributions to group climate; OR Student did not work with team effectively to complete the activity	Student did not contribute to a positive group climate; AND Student was not cooperative with team to complete the activity; AND Student did not help to set up or clean up shared space
Knowledge Resources	Student's contribution to group work demonstrated a deep understanding of the material; AND Student helped group to question the information provided, examine their own assumptions, and consider multiple points of view	Student's contribution to group work demonstrated a surface level understanding of the material; OR Student did not help group to question the information provided, examine their own assumptions, and consider multiple points of view	Student's contribution to group work showed poor understanding of the material; AND Student did not help group to question the information provided, examine their own assumptions, or consider multiple points of view

Note. The rubric was partially adapted from “VALUE Rubrics” (Association of American Colleges and Universities, 2009).

Participants and Data Collection

Student participants were generally 18-22 years of age and represented diverse majors and year levels. Data were derived from standard course assessments and evaluations and represent retrospective analysis of de-identified course data. Collection occurred throughout the semester through three separate mechanisms: (1) Student academic performance (exam scores) was analysed across three instructional approaches in PSYC2200 over several semesters. Data was collected across three consecutive semesters: Spring 2022 (Knowledge Flow), Fall 2021 (in-person traditional lecture), and Spring 2021 (online traditional lecture). All exams used questions randomly pulled from identical test banks. (2) Student feedback was collected through course evaluations in PSYC2200 and another psychology course taught using this design (Introduction to Cognition PSYC2150). (3) Reflections from Teaching Assistants (TAs) and informal observations of classroom dynamics by instructors were collected. UTAs completed a feedback survey between 6-18 months after their UTA experience to assess their experiences.

Data Analysis

Student exam scores were analysed using 1-way ANOVA to compare outcomes between pedagogical approaches. In order to measure student inclusion and classroom experience, surveys assessing students' sense of belonging/engagement in the courses and teaching evaluations with student comments were compared between traditional and active learning formats using advanced Natural Language Processing techniques in both this course and a separate large course. Qualitative feedback from students and teaching assistants was analysed thematically to identify common patterns using regarding course experience, sense of belonging, and learning effectiveness.

Program Overview

In-person course sessions for the PSYC2200 active learning course were carefully designed to target concepts that students traditionally struggle with, while incorporating inclusive teaching practices. Eleven sessions over the course of the semester included:

1. **Cranium® Dark Description:** A get-to-know-you game designed to break the ice and introduce students to each other (Kilanowski, 2012).
2. **Neuroscience in the Media Description:** Examination of neurorealism and neuroessentialism related to media portrayals of neuroscience compared to peer-reviewed journal articles, assessment of personal attitudes about neuroscience, and drawing of a neuron (Racine et al., 2010).
3. **Action Potential Game Description:** Group activity to understand the components and processes of an action potential through an interactive game with specific answer choices (Machado et al., 2018).
4. **Synapse Play Description:** Performing a synaptic play activity where students simulate serotonergic and dopaminergic synapses and learn about drug effects on synaptic function (Aubusson et al., 1997; Young, 2020).
5. **Play Doh Brain Description:** Building a brain model using Play-Doh to understand brain structure and directional terms (Akle et al., 2018).

6. **Case Study of Ming-Na Description:** Role-playing a case study of a woman born without a cerebellum, including cranial nerve function assessment and motor reflexes evaluation (adapted from Brielmaier, 2016).
7. **Drawing Flavors Description:** Exploration of flavour pathways using Bamboozled Jelly Belly beans, as students peer-teach both taste and smell sensory pathways by drawing (Koh et al., 2018; Quillin & Thomas, 2015).
8. **Motor Neuron Pom-Pom Game Description:** Interactive game using pom poms to represent neurotransmitters and their effects on brain regions, including mechanisms of ALS and the impact of L-dopa on Parkinson's disease (Carvalho et al., 2019).
9. **Sleep Escape Room Description:** Escape room challenge where students use knowledge about circadian rhythms and sleep to solve problems and escape within an hour (Nakashyan & Clabough, 2023).
10. **Endocrine Creative Cases Description:** Designing and presenting creative cases about which hormone is the most important hormone (Berger, 2008)
11. **Learning and Memory Wiki Article Generation Description:** Includes reflection on neuron drawings and sentence completions from the start of the course, and contribution to knowledge creation about pedagogical tools/learning through the creation of a group Wikipedia style article (Utecht & Keller, 2019).

Activities were grounded in published pedagogies and intentionally varied to incorporate multiple learning modalities (visual, auditory, gaming, kinaesthetic, collaborative, individual) and reduce barriers for students often found in traditional lecture formats. This multimodal approach, where perception is not limited to one mode of processing, is important for all learners, but particularly supports students with different background knowledge, prior instruction types, and past academic preparation (Rose & Meyer, 2002). Each activity also had an element of choice involved to accommodate those with lower social comfort levels. Table 2 depicts Knowledge Catalysts woven throughout the course structure.

Table 2

PSYC2200 Course Elements Based on Knowledge Catalysts

Knowledge Catalyst	Course Elements and Implementation
Meet Me (Neural level): Scaffolding structure	Weekly in-class activities with spiral progression gradually shifted responsibility to students. Consistent course structure and rubrics provided multiple entry points to complex content. Course progression built systematically from basic neural functioning to complex behaviours, while low-stakes quizzes ensured preparation before active learning sessions. Flexibility in grading through drop-lowest-score policies provided structure with adaptability, complemented by explicit syllabus study habit guidance and ongoing office hours.
See Me (Self level): Fostering belonging and recognition	An explicit belonging statement was in the syllabus, while stable 9-student table groupings fostered community. Nametags during sessions ensured individual recognition, and UTA-assigned engagement scores acknowledged student participation. The syllabus recognised how various factors including social identities, visible and invisible disabilities, family circumstances, physical location, and mental health affect learning. The TA training emphasised inclusive practices, creating a system to recognise and address barriers to inclusion in real time.
Show Me (Family level): Modelling processes	In-person sessions with hands-on activities demonstrated concepts through creative approaches. UTAs served as accessible peer models for students who might have been intimidated by authority figures. Activities like the Action Potential Game, Synapse Play, and Play-Doh Brain modelling allowed hands-on demonstration of neural processes. The Ming-Na case study offered role-playing for neurological concept application, and the Pom-Pom Motor System activity allowed

Knowledge Catalyst	Course Elements and Implementation
	students to recreate motor system dynamics as a game. TA training explicitly modelled teaching skills and students were encouraged to teach peers during activities.
Motivate Me (Community level): Connecting to real-world meaning	In-person sessions employed multiple learning modes to increase engagement with difficult concepts. The Neuroscience in the Media activity connected social content to students' experiences, while applications like Drawing Flavors linked abstract concepts to tangible experiences. Gamification in the Sleep Escape Room allowed students to solve problems using information from the lectures. Creative Cases assignments allowed students to design funny hormone-related scenarios, connecting content to meaningful applications.
Trust Me (Organisation level): Building trust through exploration	Asynchronous recorded lectures allowed students to access, rewatch, and control learning pace on their schedule. Flexible weekly quiz due dates accommodated varied obligations. Students self-graded on the first Engagement Rubric to ensure they knew how they were being assessed in class. Reflection-based activities valued students' course experiences as contributions to pedagogical knowledge, and students could choose the role they played in classroom activities. The Synapse Play allowed students to physically figure out neuronal communication and teach each other how to interrupt it with drug mechanisms of action. An optional 40-day meditation assignment trusted students to explore alternative learning approaches, while multiple TA and instructor support options throughout the week encourage help-seeking when needed.
Connect Me (Region level): Fostering collaboration	Stable nine-student table groupings created consistent communities for connection. Undergraduate TAs bridged current students with those who previously succeeded in the course. Engagement scores reinforced the importance of community participation. The UTA training course established a collaborative network focused on inclusive practices. In-person sessions emphasised peer connections and collaborative problem-solving, supported by multiple teaching team contact points creating a comprehensive support network.
Integrate Me (Humanity level): Reflection and integration	Knowledge check quizzes ensured content processing before active learning sessions. Hands-on activities provided multiple learning modes to help integrate difficult concepts. Meditative activities were often used at the beginning of the class periods. Beginning and ending reflection on their neuron drawings and attitudes about neuroscience were designed to allow students to see their own growth. The UTA course integrated teaching theory with practice, while the optional meditation assignment requires reflection on the student's personal journey over a semester. The final wiki article generation activity focused on knowledge creation specifically about how the brain responds to the pedagogical tools used for each activity, completing the integration cycle.

Results

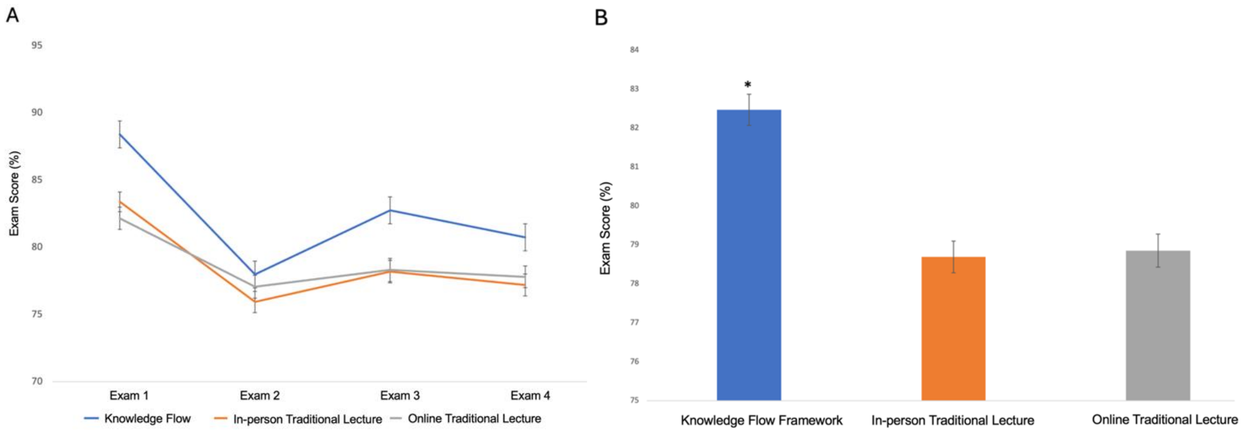
Performance Evaluation of New Approach

Test scores in the Knowledge Flow model were significantly higher compared to both traditional in-person lectures and the online-only version of the course. One-way ANOVA revealed a significant difference ($p<0.0001$) with the Knowledge Flow approach yielding higher scores (mean 82% ±0.40 SEM, n = 771 exams) than either in-person lecture only (mean 79% ±0.41 SEM, n=1071 exams) or online lecture only (mean 79% ±0.42 SEM, n = 950 exams) formats (Figure 7).

The Knowledge Flow format showed significant improvements over traditional lecture formats on surveys assessing students' sense of belonging/engagement in the courses and teaching evaluations with student comments, with particularly strong effects on learning experience and engagement in both this course and a separate large course taught using this design (Introduction to Cognition PSYC2150) [published separately (Teles & Clabough, 2024)].

Figure 7

Exam Scores in the Pilot Knowledge Flow Course



Note. Course content delivery using the Knowledge Flow framework (blue) increased test scores over in-person large lecture format (orange) or online asynchronous video lecture format (grey) in a large introductory neuroscience course across all four regular exams (A) and on the mean exam scores for each student (B) (by 1-way ANOVA, $p<0.0001$, Knowledge Flow mean 82% ±0.40 SEM; in-person lecture only 79% ±0.41; online lecture only 79% ±0.42).

Undergraduate Teaching Assistant (UTA) Experience

UTAs in PSYC2200 were administered a feedback survey between 6-18 months after their UTA experience to assess their experiences (n=7 respondents). This was the first UTA experience for the majority of these students (57%). UTAs who responded rated the TA experience as valuable to learning how to teach and facilitate learning in a classroom [4.43 mean ±0.30 SEM on a scale of 1 (not valuable) to 5 (extremely valuable)], as helpful for deeper understanding of the course material [4.43 ±0.20 SEM on a scale of 1 (extremely unhelpful) to 5 (extremely helpful)], and reported it enhanced their own sense of student belonging or inclusion at our university (4.14 ±0.26 SEM on a scale of 1 (extremely unhelpful) to 5 (extremely helpful).

In terms of personal development, all UTAs rated the TA experience as 3, 4, or 5 as helpful to their own personal development (4.29 mean +-0.29 SEM on a scale of 1 (extremely unhelpful) to 5 (extremely helpful)), specifically with problem-solving (71% of respondents), communication skills (86%), management skills (57%), emotional intelligence/interpersonal skills (86%), time management/organisation (71%), ability to work under pressure (57%), self-motivation (43%), adaptability/flexibility (86%), multitasking (71%) and decision-making (86% of respondents).

Although not essential, the creation of the new 1-credit "Undergraduate Teaching Experience" course contributed to the overall success of the Knowledge Flow model. UTAs were selected from applications by former PSYC2200 students who wanted to dive more deeply into the course material, gain leadership experience, pursue a career in education or science education, boost social connections, increase empathy skills, or simply have tangible experiences to discuss in a work-related context for future interviews. When GTAs were also involved with the successful implementation of UTA roles and helping teach how to teach, all parties were collectively learning together.

Sometimes in large classes, GTAs can take on a faculty-like role, whereas UTAs typically perform clerical roles with much less autonomy (Weidert et al., 2012; Wheeler et al., 2017). The role of the UTAs in the current course focused on in-class facilitation, allowing UTAs to deeply engage with both the material and the students in the course. UTA feedback from four different individuals also included: “Holding the position and getting to help other students gave me confidence regarding my own potential”, “Being a TA for this class is one of my favourite undergraduate memories”, “It also increased my passion for the topics as I could see the positive effects that my enthusiasm would have on a student’s experience/learning”, and “TAing this course was such a phenomenal experience that I sought another position as an undergraduate TA this semester, and I am specifically applying graduate programs with an emphasis on student teaching!”.

Discussion

Knowledge Flow Framework for Inclusion-Based Learning

This pilot study demonstrates that reconceptualising large introductory courses through a living systems approach can significantly improve student performance, engagement, and belonging. By implementing the Knowledge Flow framework, particularly emphasising the foundational Meet Me and See Me currents, a learning environment was created to better serve diverse student populations and address barriers to inclusion commonly found in traditional lecture courses. The current three-semester study compared performance across three instructional approaches: (a) Knowledge Flow framework (b) online asynchronous lectures, and (c) traditional in-person lectures. Results showed in-person lectures did not boost exam performance over asynchronous online lectures, while small group activities did significantly increase performance and engagement. It remains unclear whether the activities themselves or the social collaboration improved outcomes, possibly spending designated time with difficult concepts helped comprehension as focused study. However, the improvement in exam scores suggests a potential to close achievement gaps and promote equity in educational outcomes, while enhanced belonging reported by students indicates the model addresses critical psychosocial factors impacting retention among underrepresented students.

Modelling Classroom Design on Neural Processes

The brain functions as a complex living system where neurons act as nodes, transmitting information via action potentials. A remarkable feature of living systems is the recurrence of similar patterns across interconnected nested systems of varying scales. Larger patterns of educational reform can lean on neuroscience to recreate evolutionarily conserved organisational patterns found in the brain on a smaller level of scale. The Knowledge Catalysts do this by applying fundamental principles from molecular neuroscience to learning environments, including scaffold proteins (Meet Me; Good et al., 2011), autonomic nervous system balance (See Me; Forstenpointner et al., 2022), neuron growth cone direction finding (Show Me; Comer et al., 2019), structural modifications underneath synaptic plasticity (Motivate Me; Diniz & Crestani, 2023), network models for spatial working memory (Trust Me; Lim & Goldman, 2014), spatial and temporal summation in neuronal communication (Integrate Me; Leo, 2023), and even social communication and belonging (Connect Me), which can be explained using the example of cortical columns within the brain.

Humans differ from other animals with our elaborate 6-layered cortical structure, but scientists are still uncovering how neurons communicate with each other within the elaborate structure of these columns (Horton & Adams, 2005). As the brain develops in utero, each cortical column layer is created by different brain cells carefully crawling up over each other to reach their permanent places in the column, exchanging crucial neurochemical information throughout column formation (Stiles & Jernigan, 2010). This process represents community building, even when the specific language or purpose remains incompletely understood by neuroscientists. In parallel, the way that individual learners are taught to connect with themselves and others profoundly influences their learning and development, as well as the health and purpose of the emerging systems, with ripple effects into other nested areas, including family life, relationships, and future careers.

Comparison with Established Pedagogical Frameworks

The Knowledge Flow framework, emphasising Meet Me and See Me as foundational elements, offers a theoretically grounded approach to addressing barriers experienced by underrepresented students. Unlike approaches focused solely on content delivery or assessment, this model recognises that true inclusion requires attention to structure, belonging, demonstration, motivation, trust, connection, and integration. By seeing the classroom as a complex living system, we can create environments that honour the whole person and promote interconnection, while aligning with differentiated instruction and best practices in instructional design, including that of demonstration, real-world problems, and application (Merrill, 2002).

The Meet Me Knowledge Catalyst provides scaffolding necessary for navigating complex academic environments, which is particularly crucial for students from disadvantaged backgrounds with less exposure to academic norms. This addresses validation theory, which posits that non-traditional students need explicit academic validation to develop confidence (Rendon, 1994). Meet Me creates this validation through clear scaffolding that builds competence progressively rather than assuming prior knowledge or cultural capital.

The See Me Knowledge Catalyst addresses the well-documented importance of belonging for student success, particularly for underrepresented minorities and first-generation students (Strayhorn, 2012). Research shows something that we have all experienced in learning settings: belonging is a prerequisite for academic engagement among marginalized populations and social integration is critical for student retention (Hurtado & Carter, 1997; Steele, 1997; Tinto, 2012; Walton & Cohen, 2011). See Me creates conditions where students feel seen, valued, and welcomed as legitimate members of the academic community.

The Knowledge Flow framework shares some elements with other established approaches. While Universal Design for Learning (UDL) provides multiple pathways to accessibility (Al-Azawei et al., 2016; Rose & Meyer, 2002; Tobin & Behling, 2018), UDL focuses on accommodations, while Knowledge Flow positions scaffolding (Meet Me) and belonging (See Me) as prerequisites for transformational learning and sees the classroom as a living system where energy flows. Communities of Practice established social learning's importance (Wenger, 1998), but the Knowledge Flow framework elevates belonging from a component to an essential foundation.

While sharing Culturally Responsive Teaching's commitment to inclusion (Gay, 2018; Ladson-Billings, 1995), Knowledge Flow integrates cultural responsiveness within a systems view where student identity becomes part of holding the whole person within an interconnected learning community. The framework allows for holistic, simultaneous use of multiple evidence-based approaches to support a state of wonder that arises from learning without coercion.

Wonder and Well-being in Learning Systems

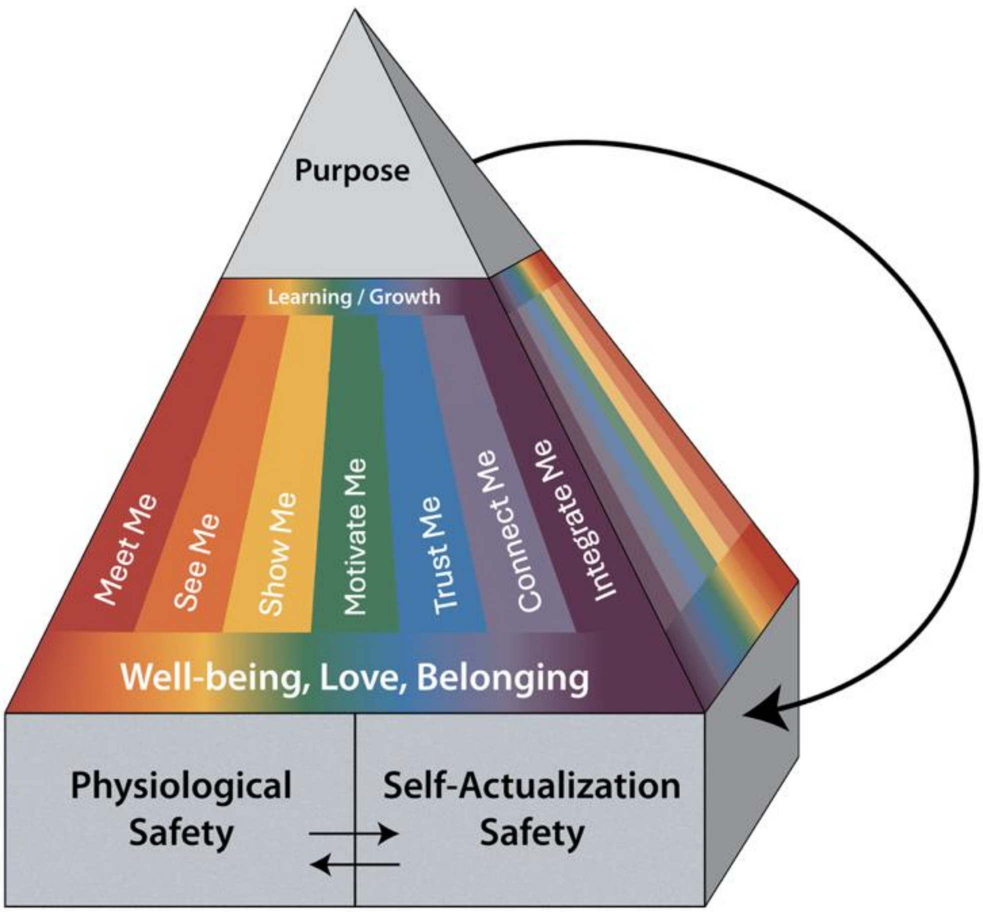
Our brains are designed to be shaped through experience-dependent synaptic plasticity as we interact with knowledge in multiple forms. Unlike the way behaviourism misses learning's beauty, wonder is joyful exploration that is opt-in, pleasant, and leads to self-realisation (L'Ecuyer, 2014). Wonder requires frameshifts to accommodate new information, which describes the basic processes of learning itself (Li et al., 2019; Stellar et al., 2018). Though consciousness means many things to academics in diverse disciplines, the simplest definition is just the ability to be present and aware, and the Knowledge Flow framework seeks to cultivate this quality through how we learn. I have observed wonder to be an emergent property at the level of consciousness, experienced in classrooms only when the Knowledge Catalysts are present, allowing the Knowledge Currents to circulate and the torus shape to emerge in the felt experience. Wonder creates internal conscious connections to self, and the Knowledge Flow approach restructures education to bring joy by placing self-actualisation at learning's core.

Maslow's Hierarchy of Human Needs (Maslow, 1943, 1969) is reimagined as a cycle rather than a ladder. Maslow postulated that "basic human needs are organised into a hierarchy of relative prepotency" where "gratification becomes as important a concept as deprivation in motivation theory, for it releases the organism from the domination of a relatively more physiological need, permitting thereby the emergence of other more social goals" (Maslow, 1943, p. 375). The suggestion that human needs at the base of the pyramid must be met before needs at the top can be met conflicts with how self-actualisation connects to safety, and the traditional pyramid interpretation may have misrepresented Maslow's original, more nuanced understanding of how human needs interact. I propose two basic human needs 1) self-actualisation safety (internal) and 2) physiological safety (external), moving self-actualisation alongside physiological safety at the foundation. At the pyramid's top sits learning/growth and purpose, the culmination of well-being and self-work (Figure 8).

This shift is fundamental to designing human living systems, the more safety we cultivate, the more open the flow through our nested systems becomes. The PSYC2200 course design implements this framework by addressing both types of safety needs, incorporating all seven Knowledge Catalysts through specific course elements, emphasising well-being, and connecting learning to meaningful purpose. Here, the goal of a classroom system is a sense of inclusion, "this learning is for *me,"* without which meaningful learning cannot occur.

Figure 8

The Knowledge Flow Model of Human Well-being in Learning Contexts



The model (Figure 8) rearranges and adds to Maslow's original hierarchy of needs, incorporating elements of social connection, personal development, and holistic well-being into an interconnected, continuous framework, supported by the Knowledge Catalysts. The redesign positions Self-Actualisation Safety as foundational and coexisting with Physiological Safety, which are dually required for humans to experience true well-being, love, and belonging. The Knowledge Catalysts (Meet Me, See Me, Show Me, Motivate Me, Trust Me, Connect Me, and Integrate Me) function as seven different ways for humans to find Purpose through Learning and Growth, which are connected back to the base to illustrate the cyclical relationship between fulfillment of higher needs and reinforcement of foundational safety. Here, self-actualisation is not the highest level of development for humans, but rather a basic human need.

Living systems theory can also inform leverage points where small deliberate change can make large changes to create a healthier system, including reconfiguring structure/flow, patterns of relationships, attention to system goals, and embracing emerging paradigms (Birney, 2021; Meadows, 1999). Educational systems have historically sacrificed resilience for stability, predictability, and assessment ease, creating approaches that falter when exposed to stressors like pandemics, emerging technologies, and decreasing student well-being. Knowledge Flow restores resilience by designing for feedback and evolution based on one of the most resilient structures of all: the brain. Traditional educational feedback loops primarily stabilise the existing systems, while living systems enable self-correction and innovation. Knowledge Flow incorporates multiple feedback mechanisms allowing the environment to adapt to student needs rather than forcing students to adapt to rigid systems. This self-organising capacity means learning environments can evolve to address barriers experienced by diverse populations without requiring a complete redesign for each cohort, as long as Meet Me and See Me are established.

The Knowledge Catalysts are tools to build structure/function relationships. When learning experiences are designed with all the Knowledge Catalysts, then the Knowledge Currents will arise as an emergent property when the entire circuit is connected, resulting in the torus. The Knowledge Catalysts of Meet Me and See Me are the minimum viable product for a classroom but using *only* those will just generate Knowledge Current 1 (BUILD) and will keep a classroom closer to the 2D linear system of learning. Adding the other Knowledge Catalysts will enable the more emergent properties of learning to flow and maximise opportunities for learning. By focusing on these core implementation strategies, instructors can adapt the Knowledge Flow framework to various institutional contexts while maintaining its essential elements of structured scaffolding and belonging that support diverse learners.

Limitations and Future Directions

Any active learning technique has the potential to improve outcomes over traditional lectures, but different active learning techniques will have varying effectiveness based on the prior educational experiences, social context, and personal needs of the individual, hence the comprehensive approach of the Knowledge Flow framework for inclusive effectiveness. The presented data have limitations, as many different pedagogical approaches are combined into a single framework, specific class demographic information was not collected, and the control groups were courses from previous semesters without random assignment.

Future research on the Knowledge Flow framework should focus on four key areas. First, longitudinal studies tracking diverse student cohorts through their academic careers would allow evaluation of the long-term impact of this approach on retention, graduation rates, and post-graduation outcomes for represented students. Research should collect detailed demographic data to assess how effectively the framework addresses specific barriers faced by different student populations. Second, measures of well-being and self-actualisation safety should be assessed to see if the Knowledge Flow framework can improve student well-being through the tool of well-designed learning (Deci & Ryan, 2008; Howell & Buro, 2015). This is particularly important, as anxiety, depression, and suicide ideation are at staggeringly high levels in college age students (Zhou et al., 2023). Educators are in a unique first-responder position to implement learning redesign with well-being as a priority.

Third, while a linear learning approach is not ideal for most students, it disproportionately impacts students from underrepresented backgrounds, first-generation students, and those who may have had fewer academic opportunities prior to university entry (Eddy & Hogan, 2014). Large lecture formats often contribute to feelings of anonymity, reduced interaction with instructors, limited peer engagement, and ultimately, a diminished sense of belonging among students from diverse backgrounds (Rainey et al., 2018). The resultant lack of inclusion represents a significant barrier to academic success and retention for many students, especially those from disadvantaged groups (Murphy & Zirkel, 2015). Given these differential impacts, alternative pedagogical approaches, such as the torus model proposed here, may be particularly beneficial for underrepresented student populations, although this hypothesis requires empirical investigation in future research. Lastly, conducting implementation studies across varied disciplines and institutions would help refine the model's adaptability outside neuroscience classrooms, exploring how the Knowledge Catalysts (specifically Meet Me and See Me) could be customised as a foundation for inclusive learning environments in STEM fields, humanities, and professional programs.

Conclusion

A key tenet of both living systems theory and neuroscience is that strength and resiliency arise through diversity and redundancy. Knowledge Flow brings together living systems theory with practical teaching approaches, grounds educational practice in brain science, and reimagines human educational needs as cyclical and interconnected, rather than linear. By prioritising scaffolding (Meet Me) and belonging (See Me) as foundational elements, the Knowledge Catalysts create the conditions necessary for all students to engage fully in the learning process, regardless of their background or prior educational experiences. As higher education institutions worldwide strive to widen participation and promote equity, the Knowledge Flow approach provides a valuable model for transforming large introductory courses from potential barriers to gateways for success among diverse student populations.

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