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A Conceptual Framework for Interdisciplinary Curriculum Design: A Case Study in Neuroscience

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Teaching of interdisciplinary fields of study poses a challenge to course organizers. Often interdisciplinary courses are taught by different departments, and hence, at best provide a multidisciplinary overview. Scientific progress in neuroscience, for instance, is thought to depend heavily on interdisciplinary investigations. If students are only taught to think in particular disciplines without integrating these into a coherent framework to study the nervous system, it is unlikely that they will truly develop interdisciplinary thinking. Yet, it is this interdisciplinary thinking that is at the heart of a holistic understanding of the brain. It is, therefore, important to

develop a conceptual framework in which students can be taught interdisciplinary, rather than multidisciplinary, thinking. It is also important to recognize that not all teaching needs to be interdisciplinary, but that the type of curriculum design is dependent on the aims of the course, as well as on the background of the students. A rational curriculum design that aligns learning and teaching objectives is, therefore, advocated.

Key words: Neuroscience; Interdisciplinary; Curriculum Design; Rationale Curriculum Planning; Spiral Curriculum; Expert Learning; Novice to Expert; Multi-disciplinary, Teaching

NEUROSCIENCE: AN INTERDISCIPLINARY FIELD OF STUDY

Neuroscience is the interdisciplinary study of the nervous system. Diverse disciplines, such as psychology, pathology, molecular biology and even computer science converge their efforts to understand how the nervous system works and produces behavior. The clinical relevance of these studies is captured in neurology and neuropathology (often jointly termed clinical neuroscience), as well as psychiatry. Each discipline has particular methods and techniques that are appropriate to study their area of interest. These methods often focus on particular parts of the nervous system or their functions, such as the physiological basis of the withdrawal reflex in sea slugs (i.e., electrophysiology) or the neuronal loss in the nigrostriatal pathway and its importance to Parkinson's disease (i.e., histopathology). However, these diverse areas often do not directly relate to each other (cross-disciplinarity) and provide a fragmented viewpoint of the nervous system and its functions.

To ensure steady progress in our holistic understanding of the nervous system, it is imperative that new generations of scientists are educated in the interdisciplinary nature of neuroscience, rather than merely within a single discipline (i.e., uni-disciplinary) (Ramirez, 1997; Collins, 2002). Although a multidisciplinary approach (i.e., different disciplines working side-by-side to address a common circumscribed topic) is more desirable than a cross-disciplinary study (i.e., engaging different disciplines without focusing on a common issue), it is trans-disciplinary investigations (i.e., transcending traditional

Scientific Orientation	Definition
Uni-disciplinarity	A single discipline works together to address a common problem.
Cross-disciplinarity	More than one discipline work side-by-side on related problems without involving each other to solve their problems. There is no attempt at discourse with other disciplines and practitioners are confined within their discipline.
Multi-disciplinarity	More than one discipline work independently on a common problem. There is little commonality in terminology and methodology to address the common problem. Practitioners will only work within their discipline, but recognize that there are different facets to a common problem.
Trans-disciplinarity	More than one discipline work together on a common problem with some overlap in methodology and terminology. Some integration between disciplines occurs that lead to common concepts, potentially new models and theories, but there is no complete overlap. Practitioners still feel mostly confined to their traditional disciplines.
Inter-disciplinarity	More than one discipline work integrally on common problems. Disciplines are synthesized and extend discipline-specific theories and concepts with potentially novel methodology that is relevant to all involved disciplines. Practitioners feel at ease in all the involved disciplines.

Table 1. An overview of definitions used to classify scientific orientation, based on (Rosenfield, 1992; Stokols et al., 2008).

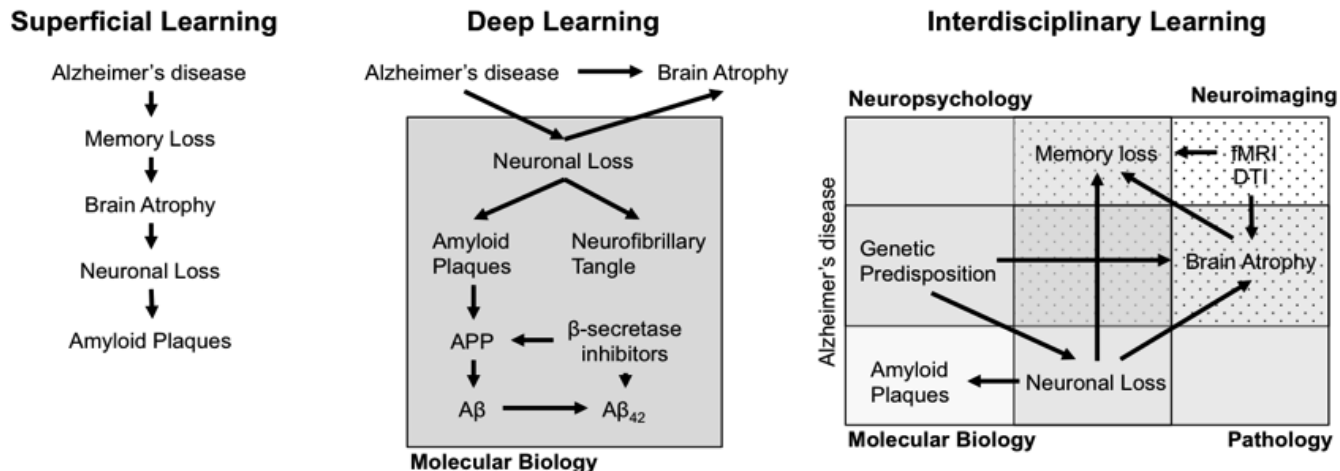


Figure 1. Interdisciplinary learning. A simplified illustration of different learning processes. Superficial learning is characterized by a very limited understanding of how particular aspects link together and typically only a few connections between different concepts is evident. Deep learning in contrast is characterized by a well-established conceptual representation of how particular elements link together, but also provides a certain level of detail for each concept that is absent from superficial representation. Knowledge is typically restricted to a single discipline (e.g., molecular biology). Interdisciplinary learning can contain aspects of both superficial and deep learning. However, importantly an interdisciplinary understanding is exemplified by understanding how particular elements from one discipline are also relevant to another and how they are part of the same problem. Typically integration here occurs across different disciplines (e.g., molecular biology and neuroimaging), but also across scale (e.g., understanding that A β aggregates cause neurodegeneration that leads to a loss of neurons that in turn causes memory loss, based on (Nagy, 2005).

boundaries of scientific disciplines without fully integrating with another discipline) that are the starting point to overcome the limitations that individual disciplines face while studying the nervous system. Trans-disciplinary scientists are overcoming traditional gaps in terminology, methodology, and analytical approaches. However, they do not fully integrate and adopt the expertise of another discipline (Table 1). It is the *integration* of the analytical and methodological strengths, as well as a common terminology, across multiple disciplines that is required to advance an inter-disciplinary field of study, such as neuroscience (<http://neuroscienceblueprint.nih.gov>). Although neuro-science, in practice and in teaching, today is a mix of these different disciplines, it is the interdisciplinary approach that poses the greatest challenge to teach neuroscience within a coherent framework (Ramirez, 1997; Pellmer and Eisenberg, 2000; Holley, 2009).

Interdisciplinary teaching and learning is a challenge to both teachers and students (Woods, 2007; Bleakley et al., 2011). Teachers are often specialized in a particular discipline and find it challenging to engage with other teachers, as there is a lack of a common vocabulary and educational vision. However, it is this competence in communication between disciplines that is at the heart of interdisciplinary teaching (Woods, 2007). Teachers need to share a common vision and ideology to design an appropriate curriculum for students. If there is a lack of coherence in the teaching curriculum due to miscommunication between teachers from different disciplines, it is likely that students will get a fragmented

view of neuroscience that promotes superficial learning, rather than interdisciplinary learning (Figure 1). There is a need for a consistent framework within which structured learning can occur and allow students to assimilate complex ideas into a cohesive knowledge structure (Biggs, 2003). The diversity and different viewpoints from multiple disciplines is also an asset to the curriculum as information is presented multiple times within different contexts potentially fostering a deeper learning (i.e., a robust knowledge and understanding of a discrete topic). Additionally, increasing links between apparently disparate and complex ideas will be essential to create an interdisciplinary learning process (Lattuca et al., 2004; Lawson, 2006). Indeed, an interdisciplinary neuroscience curriculum aims to link apparently disparate types of information into a continuous and coherent knowledge structure. Therefore the curriculum design requires thorough planning to provide an appropriate learning environment for students.

It is important to note that the curriculum is more than just the content to be taught on an academic course (Fraser and Bosanquet, 2006). Curriculum design also includes the overall organization of the learning process (i.e., the structure of the teaching program), the teaching methods (e.g., practicals, presentations, discussions) and the content of what is being learnt, as well as the assessments that are used to determine if indeed learning took place (Helsby, 1999). Recent initiatives have aimed to develop blueprints for neuroscience teaching, but have mostly focused on the content that should be included within an undergraduate degree (Ramirez et al., 1998;

Higher Degree	BSc	MSc	PhD
FQ-EHEA Level	First Cycle	Second Cycle	Third Cycle
FHEQ Level	6	7	8
Outcomes & Achievements	<ul style="list-style-type: none"> •a systematic understanding of key aspects of their field of study, including acquisition of coherent and detailed knowledge, at least of which is at, or informed by, the forefront of defined aspects of discipline •an ability to deploy accurately established techniques of analysis and enquiry within a discipline •a conceptual understanding that enables the student: <ul style="list-style-type: none"> - to devise and sustain arguments, and/or solve problems, using ideas and techniques, some of which are at the forefront of a discipline - to describe and comment upon particular aspects of current research, or equivalent advanced scholarship, in the discipline •an appreciation of the uncertainty, ambiguity and limits of knowledge •the ability to manage their own learning, and to make use of scholarly reviews and primary sources (e.g., research articles and/or original materials appropriate to the discipline) 	<ul style="list-style-type: none"> •a systematic understanding of knowledge, and a critical awareness of current problems and/or new insights, much of which is at, or informed by, the forefront of their academic discipline, field of study or area of professional practice •a comprehensive understanding of techniques applicable to their own research or advanced scholarship •originality in the application of knowledge, together with a practical understanding of how established techniques of research and enquiry are used to create and interpret knowledge in the discipline •a conceptual understanding that enables the student: <ul style="list-style-type: none"> - to evaluate critically current research and advanced scholarship in the discipline - to evaluate methodologies and develop critiques of them and where appropriate, to propose new hypotheses 	<ul style="list-style-type: none"> •the creation and interpretation of new knowledge, through research or other advanced scholarship, of a quality to satisfy peer review, extend the forefront of the discipline and merit publication •a systematic acquisition and understanding of a substantial body of knowledge which is at the forefront of an academic discipline or area of professional practice •the general ability to conceptualize, design and implement a project for the generation of new knowledge, application or understanding at the forefront of the discipline, and to adjust the project design in the light of unforeseen problems •a detailed understanding of applicable techniques for research and advance academic enquiry
Abilities	<ul style="list-style-type: none"> •apply methods and techniques to review, consolidate, extend and apply knowledge and understanding and initiate and carry out projects •critically evaluate argument, assumptions, abstract concepts and data to make judgment and to frame appropriate questions to achieve a solution – or identify a range of solutions – to a problem •communicate information, ideas, problems and solutions to both specialist and non-specialist audiences 	<ul style="list-style-type: none"> •deal with complex issues both systematically and creatively, make sound judgments in the absence of complete data, and communicate their conclusions clearly to specialist and non-specialist audiences •demonstrate self-direction and originality in tackling and solving problems, and act autonomously in planning and implementing tasks at a professional or equivalent level •continue to advance their knowledge and understanding, and to develop new skills to a high level 	<ul style="list-style-type: none"> •make informed judgment on complex issues in specialist fields often in the absence of complete data and be able to communicate their ideas and conclusions clearly and effectively to specialist and non-specialist audiences •continue to undertake pure and/or applied research and development at an advanced level, contributing substantially to the development of new techniques, ideas or approaches
Transferable Skills	<ul style="list-style-type: none"> •Initiative and personal responsibility •Decision-making in complex and unpredictable contexts •Learning ability to undertake appropriate further training 	<ul style="list-style-type: none"> •exercise of initiative and personal responsibility •decision-making in complex and unpredictable situations •independent learning ability required for continuing professional development 	<ul style="list-style-type: none"> • exercise of personal responsibility and largely autonomous initiative in complex and unpredictable situations in professional or equivalent environments.

Table 2. Criteria to define higher education degrees (B.Sc. – Bachelor of Science; M.Sc. – Master of Science; PhD – Philosophiae Doctor) according to the UK Quality Assurance Agency (Anonymous, 2008). The Framework for Higher Education Qualifications in England, Wales and Northern Ireland (FHEQ) defined various levels of education degrees that can be found within the UK. It is important to note that within a single education system, higher education also encompasses other advanced degrees, such as a foundation degree (level 5). However, these qualifications are often specific to one educational system. In contrast, the Framework for Qualifications of the European Higher Education Area (FQ-EHEA) provides a different classification system that encompasses all higher degrees recognized by European countries and serves as a means to classify degrees from different education systems.

Degree	Skill	Knowledge	Quality	Autonomy	Complexity	Context
BSc	Novice	Minimal	Unsatisfactory level	Requires close supervision	Little conception of complexity	Tends to see actions in isolation
	Beginner	Working knowledge of key aspects	Simple tasks performed at acceptable level	Can perform simple tasks independently, but requires supervision of overall tasks	Appreciates complex situations but only able to achieve partial resolution	Sees actions as a series of steps
	Competent	Good background and working knowledge	Fit for purpose but requiring refinement	Able to achieve most tasks using own judgment	Copes with complex situations through deliberate analysis and planning	Sees actions at least partly in terms of longer goals
MSc	Proficient	Depth of understanding of discipline and practice	Routinely achieves acceptable standard	Able to take full responsibility for own work	Deals with complex situations holistically, decision making more confident	Sees overall picture and how individual actions fit within it
PhD	Expert	Authoritative knowledge of discipline and deep tacit understanding across practice	Excellence achieved with relative ease	Able to take responsibility for going beyond existing standards and creating own interpretations	Holistic grasp of complex situations, moves between intuitive and analytical approaches with ease	Sees overall picture and alternative approaches, vision of what may be possible

Table 3. A comparison of learning characteristics of higher education degrees with the evolution from a novice to an expert (based on (Dreyfus and Dreyfus, 1980; Anonymous, 2003).

Wiertelak and Ramirez, 2008). Defining an appropriate curriculum is crucial to specify what learning outcomes are expected of the students. These will differ markedly depending on the level of study. We therefore here discuss the conceptual framework within which an interdisciplinary curriculum in neuroscience can be designed to fulfill the different requirements of the scientific and professional community.

CONSIDERATIONS FOR UNDERGRADUATE AND POSTGRADUATE CURRICULUM DESIGN – FROM NOVICE TO EXPERT

Curriculum design for neuroscience courses that lead to academic degrees (i.e., the awarded qualification at the end of a defined learning period/course) is geared towards teaching a solid knowledge base of the nervous system, develop appropriate analytical skills (including laboratory techniques), but also to establish the students' ability to control their own learning. Although degrees in neuroscience are awarded in a variety of universities and colleges, the learning outcomes of the different courses (i.e., implementation of a degree at a given institution) will depend on the specific focus/interest of the university and department (Ramos et al., 2011). The learning outcome will depend on whether students are being prepared, for instance, to proceed to a PhD program or if the course is mainly designed to prepare students to become technicians in a laboratory (Austin, 2002; Estes, 2007). Although curriculum design needs to account for these different aims, curriculum design will also be highly dependent on the level of the university degree. The

specific learning outcomes between a BSc, MSc and PhD, irrespective of the focus of the university, will require an increasingly more sophisticated scholastic ability, but also more independence in the students' learning (Table 2).

A curriculum developing a scholastic ability in neuroscience needs, therefore, to also account for the students' prior knowledge. In the case of undergraduates, it is unlikely that these students will have any prior knowledge of neuroscience and hence they need to be considered novices. In contrast, at the post-graduate level some students might have taken a prior undergraduate degree in neuroscience, and hence, would have a solid knowledge base to build on. With these students, it should be possible to then further develop their skills to a more proficient level (MSc courses) and eventually to an expert level (PhD programs). Based on the Dreyfus model (Dreyfus and Dreyfus, 1980), we can then revisit the aims of undergraduate and post-graduate courses to define an undergraduate course as a course that develops novices into competent professionals, whereas a Master's degree produces proficient scientists that can eventually become experts within a PhD program (Table 3) (curriculum design for PhD programs is very specific and goes beyond the scope of the current discussion). As some neuroscience courses will recruit students from other disciplines, such as computer science or philosophy, to foster inter-disciplinarity; these courses, therefore, cannot presume the same background in neuroscience between all students. These courses will require a different curriculum design compared to those where students had a previous exposure to a more general neuroscience training (see below). Nevertheless, at the same time, these courses

need to also fulfill the learning outcomes that are required to award a neuroscience degree and ideally aim to provide an inter-disciplinary view of the field.

One of the challenges of modern curriculum design is therefore to provide a learning environment that is flexible, provides efficient learning and, at the same time, is economically viable. Often flexibility and economical viability are tightly linked, as costs are directly linked to the number of students and courses that can be taught using the same resources (Grundy, 1987; Estes, 2007; Whittaker and Akers, 2009). However, to ensure a continued success of these courses, their focus needs to be on efficient learning, rather than purely on it being economical. Although some learning is merely a reflection of how much factual information students recall on a particular subject, a more modern perspective on learning would require that students evolve from novices to experts by demonstrating an ability to manipulate knowledge (Kinchin and Cabot, 2010). As such, novice students would acquire a solid base of core factual information that reflects the wider aspects of their subject, but as the curriculum progresses they specialize to become experts by developing skills that can be applied to a variety of factual information (Carraccio et al., 2008). Expertise in this case would not be just recollecting a series of facts, but would additionally involve the students' ability to use this knowledge in novel ways and generate a new understanding/knowledge through research, ideally by transcending traditional boundaries of scientific disciplines (Bennett et al., 2000; Prideaux, 2003). These aspects, therefore, need to be reflected in an appropriate curriculum design.

1.	Establishing the learning needs
2.	Defining learning objectives
3.	Determine an appropriate subject content
4.	Selecting participants
5.	Determining the best schedule
6.	Selecting appropriate facilities
7.	Selecting appropriate instructors
8.	Selecting and preparing audio-visual aids
9.	Coordinating the program
10.	Evaluating the program

Table 4. Kirkpatrick's (1994) 10 generic points in curriculum design.

THE PROCESS OF CURRICULUM DESIGN AND MANAGING STUDENT LEARNING

Kirkpatrick (Kirkpatrick, 1994) identified 10 generic points that should be considered in curriculum design (Table 4). These 10 points indicate the importance of planning and that curriculum design goes beyond the content of the taught material. Even before designing the curriculum, communication between the different actors (i.e., university administrators, course designer/coordinator, teachers and prospective students) is important, as aims, objectives and learning outcomes will be the most important factors that define the learning process in a top-down fashion (Prideaux, 2003). It is against these 'outcome measures' that the success of a given curriculum needs to be judged. As the course progresses from one academic year to the

next, there is a need for a re-evaluation of the designed/planned and created curriculum against the experienced curriculum (Figure 2A) (Baerheim et al., 2007). Minor or major refinements are constantly required. Ideally, the created curriculum is consistent and constructively aligned with the aims of the planned curriculum (Biggs, 2003). Constructive alignment of the curriculum implies that students will be able to generate meaning from the different activities they encounter as part of the curriculum. The success of the learning process is measured through assessment of the students' knowledge and skills in the subject, but also through their feedback on the curriculum of the course (Figure 2B).

Managing students' learning is essential for a constructive alignment of the curriculum with learning outcomes. Problem-based learning has been suggested to achieve a good constructive alignment of the curriculum for medical-based subjects (Fraser and Bosanquet, 2006; Trappler, 2006). If students are faced with professional problems, such as designing an experiment to determine if a mouse modeling Alzheimer's disease has a memory disorder, they would construct meaning out of this situation and learn how to solve a particular problem. However, this is not necessarily so, as the problems have to be very well defined and provide a clear process from which the students can learn (Tchudi and Lafer, 1996). For this, the students will need to know sufficient information to consider a particular problem, as otherwise they are unlikely to really confront the issues at hand (Schmidt, 2009). Importantly, students need to generate the outcomes/solutions to the problem to ensure that they truly engage with the problem (so called epistemic curiosity). If solutions are presented by the teacher, the students are unlikely to fully engage. There is, nevertheless, a risk in this approach that students feel lost and disengaged with the learning process. Therefore, a strong emphasis will be on the teachers and their guidance through this process (Ward and Lee, 2002). Still, it is this interaction between teachers and students that is most likely to yield the best results, although it poses a greater demand on the teachers' time and skills.

Ideally, problem-based learning would allow students to first experience a superficial learning of the subject area in which they will merely connect how different concepts relate to each other without going into the specific complexities within each particular topic (Trappler, 2006). These core or introductory sessions could also involve other aspects that enhance interdisciplinary thinking, such as historical, ethical or philosophical aspects of the field (Beck, 1986; Wiertelak and Ramirez, 2008). In advanced or specialized modules, students can engage more directly (e.g., practicals) and diversely (e.g., discussions, practicals, research projects) with the topic that will result in a more meaningful and deeper understanding (Kolb, 1984; Beattie et al., 1997). If appropriate, these specialized modules could be developed into a curriculum that re-focuses learning into a particular discipline, such as a degree in Neuroimaging, rather than a more general degree in Neuroscience (Estes, 2007). In these specialized modules, researchers can present and discuss

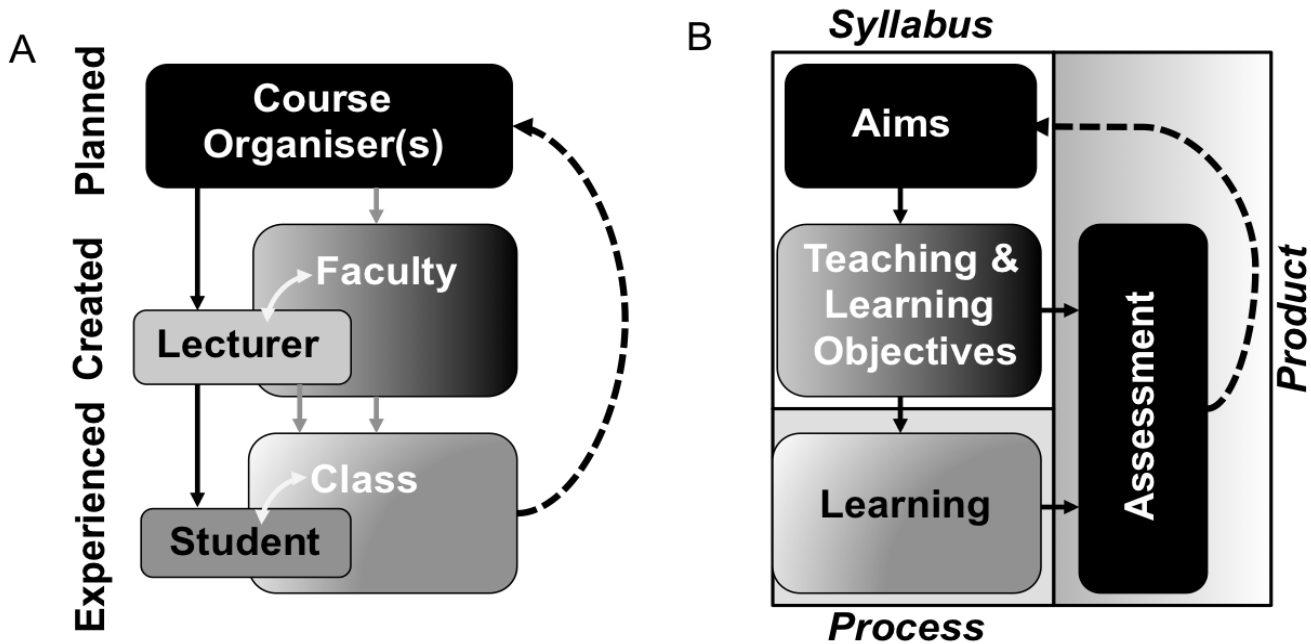


Figure 2. Curriculum Design. *A.* The curriculum typically is thought to have 3 manifestations: the planned curriculum (reflected in the aims and purposes set-out by the course organizers), the created or delivered curriculum (reflected in the day-to-day teaching methods and contents of individual sessions), and the experienced curriculum (reflected in the students learning as evidenced by the assessments). Although there is a top-down influence of the planned curriculum, upon implementation it is important that there is feedback from the experienced curriculum to adjust and update the planned and created curriculum. This engenders an iterative process of curriculum design that will refine the learning process. It is important to note that the teaching methods of individual teachers is experienced by a student in the context of the teaching by the rest of the faculty, as well as the perception and discussion of other students in the class. *B.* The course organizers base their planned curriculum on particular aims (i.e., learning outcomes) they set out to achieve as part of their course. Learning outcomes should translate into teaching and learning objectives for the various teaching sessions and together with the aims of the course provide the syllabus. Student’s learning is “the process” that is enabled by the planned curriculum and “the product” of this process is evaluated using assessment that define the performance criteria of the student(s), but also inform on the success of the planned curriculum. Ideally, the planned curriculum is constantly revised to ensure an improvement in the students’ learning.

their latest research, but students can also be asked to critically appraise a specific paper relevant to the subject or present/defend someone else’s work in this area (Cleland, 2002). This approach will allow them to critically evaluate work in this area. The designation of the course will then depend on the specific content that is taught in both the core and specialized modules (Estes, 2007). These “novice-expert” modules would allow the university to enlarge the number of courses offered (Trappler, 2006).

FROM A MULTI-DISCIPLINARY TO AN INTERDISCIPLINARY CURRICULUM

A modular approach to curriculum design is often desirable as teaching spans across several academic departments (Ackerman et al., 1976; Wiertelak and Ramirez, 2008). Nevertheless, this can lead to each module equating to a specific discipline (e.g., developmental neurobiology, neuropsychology) and is likely to result in a ‘multi-disciplinary’ curriculum structure. Under this structure, the departments are mostly independent to organize the content and structure of these individual course modules. Little integration of modules and cross-linking between

disciplines is needed. Typically modules evolve from developmental neurobiology and neuroanatomy to behavioral, cognitive and clinical neuroscience. This structure is easy to administer and can draw on existing content (commonly an introductory course for that discipline) that is administered on more discipline-focused teaching sessions. Within each module, students are provided with a general overview of the discipline and its contribution to the study of the nervous system. Typically, following this general overview, teachers will focus specifically on their area of expertise. The content and teaching methods might not be contiguous and hence could prevent the integration of material from the different modules. This structure mainly leaves integration of information to students and does not provide a structure that is conducive to integrate different disciplines, but rather regards them as parallel to each other, potentially fostering a multi-disciplinary view of neuroscience. Despite flexibility and the potential to develop expert learning, there have been concerns that a modularized curriculum can endanger coherence in learning (Bennett et al., 2000). Although, it will be obvious to students that there is some overlap between disciplines, too few opportunities are

given to students in the delivered curriculum to develop a clearly integrated view of neuroscience as an inter-disciplinary field of study. This multi-disciplinary approach to curriculum design, therefore, might be apposite for undergraduate programs or Master-level programs that aim to provide a general overview of neuroscience (Table 2), but it is unlikely to provide the level of integration that is required for an inter-disciplinary view of neuroscience (Boitano and Seyal, 2001).

An interdisciplinary curriculum needs to achieve an integration of these disparate disciplines to highlight how they all converge to answer a particular question. The development of “problem-based learning” can provide a platform that affords students to interact with techniques and theoretical constructs from a variety of disciplines (Trappler, 2006). For instance, is it the accumulation of aggregated A β proteins in the CA1 subfield of the hippocampus that leads to a cognitive impairment in patients with Alzheimer’s disease? This requires knowledge of what distinguishes aggregate forms of A β , probes neuroanatomy in terms of defining location as an important factor, but also necessitates an understanding of how one can reliably assess cognitive functions in animals and its translational relevance to patients. Confronting students repeatedly with similar issues to solve will allow them to refine their learning and improve outcomes. The specific problem or question here, however, is not of as much importance as the principle that they have to engage to solve a particular biological puzzle that requires multiple tools to provide a satisfactory answer. It is the teacher’s responsibility here to ensure that the students draw on multiple disciplines and that integration is required to provide an appropriate answer. To ensure persistent learning of this integrative approach, it is important to not overemphasize specific facts, as these are rapidly changing in modern science, but rather to develop competencies (i.e., finding the appropriate type of information to integrate). It is these competencies that are most likely to be useful if students progress in their future careers, be it in academia, industry or government (Wiertelak, 2003).

A ‘spiral’ curriculum that repeatedly exposes the students to the same aspects in a different context is likely to enhance the interdisciplinary learning and the connection between different facets of the same problem (Bruner, 1960; Masters and Gibbs, 2007). For instance, students can learn the basic principles of A β aggregation with a lecture, but this same information can be “revisited” during a discussion of animal models and their pathology and both of these can then be re-discussed within context while seeing patient’s with the disease. This forms a spiral of learning where the same information is placed within a new context that adds complexity to the acquired knowledge. Importantly, however, the re-presentation and discussion of relevant information requires planning and hence coordination over the whole curriculum.

Disciplinarity, using this approach, is de-emphasized and solving the scientific question or problem with appropriate means is accentuated. Continued assessments and reiterations of general concepts will be

needed to ensure persistent learning and inter-disciplinary thinking. Careful planning of each module in the context of the overall curriculum is central to ensure that specific aims are defined and accomplished by teaching methods. One approach to implement this progression in the curriculum are core teaching modules that involve a general overview of the subject allowing students to connect with the new material based on the variety of background information they previously acquired. The advantage of this system is that all students will have sufficient background to engage with more complex ideas and gradually learn to integrate ideas and techniques from other disciplines. Although inter-disciplinary teaching is thought to be essential to the progress of neuroscience, it is vital to acknowledge that not all students will be adept at this process and, potentially more importantly, not all students are interested in this type of learning. Some students will prefer to specialize in one specific area or technique that is relevant to neuroscience. Therefore, courses and curriculum design need to reflect the variety of students’ background, as well as their interests.

A FLEXIBLE AND RATIONAL CURRICULUM DESIGN BASED ON EXPECTED LEARNING OUTCOMES

It is important to note here that no one curriculum structure is necessarily better than another one, provided that it is based on a rational design that delivers the expected learning outcomes (i.e., “the product”). Rational curriculum design will first specify particular aims and outcomes that should be achieved by the curriculum (i.e., the planned curriculum) (Kessels and Plomp, 1999). Elements that are not relevant to these will be omitted. There is a commitment to provide an efficient learning process to achieve these aims. In general, it is thought that there are three parts to a curriculum (Figure 2): the planned curriculum, the created curriculum and the experienced curriculum (Stenhouse, 1975; Knight, 2001). The created curriculum incorporates the different teaching methods and content to achieve these aims (i.e., “the syllabus”). However, delivery of this is dependent on the teachers, also sometimes referred to as the delivered curriculum. The experienced curriculum is reflected in the learning of the students (i.e., “the process”). Typically, the learning outcomes are evaluated using various forms of assessment. However, as always, to ensure that these different ‘versions’ of the curriculum converge, communication between the different actors is key (Huber, 2002).

The main aim of curriculum design is to engage the student and to refine the learning process (Brann and Sloop, 2006). To this end, the students need to experience as many different ways as possible to interact with the same topic (i.e., neuroscience) and to assimilate interdisciplinary thinking. Often, when given a choice to engage with interdisciplinary modules, students choose to stay within their discipline or to very closely related subjects (Huber, 2002). Although this might be appropriate for some courses that restrict themselves within a

particular discipline or scientific question (e.g., neurodegeneration), it does not provide students with a more comprehensive skill set that we would define as inter-disciplinary. It is paramount for the students to be aware that they need to drive the learning process outside of their comfort zone and that curriculum and faculty are but enablers for this process.

Apart from curriculum design, specific teaching methods used within the course structure are also important aspects to direct students' learning (Bourner and Fowers, 1997). It is here also relevant to remark that neither teachers, nor students act within a vacuum, but their teaching and learning are part of a collective experience (Figure 2A). A teacher's methods of teaching are embedded and offset with the remainder of the faculty. It is, therefore, desirable for different teachers to employ a variety of teaching methods (Felder, 1993; Tanner and Allen, 2004). This will enable students with different learning styles to engage more effectively, but will also present students with different experiences of the same content (Kinchin, 2011). A student's learning experience is not only influenced by their assimilation of what is presented by the faculty, but it is also dependent on their interaction with other students (Hirschy and Wilson, 2002). An efficient and rational curriculum design for inter-disciplinary topics is, therefore, a dynamic process that requires careful planning, but also a continued engagement of both faculty and students.

CONCLUSION

Ideally, neuroscience courses should provide a varied and skilled workforce. Future employers should be able to associate particular neuroscience degrees with a student that is appropriate for their needs (Whittaker and Akers, 2009). Courses, therefore, will eventually need to define the main responsibilities associated with the student's occupation (i.e., critical work function), but they will also need to identify and measure competencies (i.e., student's key activity), determine effective performance criteria (i.e., provide performance indicators in key activities), establish an essential knowledge associated with the occupation/profession (i.e., technical/scientific facts) (Bennett et al., 2000). These aspects need to be complemented by more general competencies in key activities (e.g., adaptability of skill and knowledge), as well as desirable attitudes to the activity (i.e., ethics, professional conduct, continued professional development). These indicators would define a standard of aptitude of neuroscientists. These standards provide "practitioners" and employers with a certain quality control that allows them to choose neuroscience courses based on their current and desired aptitude, as well as on their future employability. Curriculum design is a key factor to deliver this high quality neuroscience teaching.

The conceptualizations about curriculum design illustrate strengths and weaknesses of each approach, but there is little, if any, evidence for any particular curriculum approach being measurably superior in student learning. Although there is some recent evidence that a problem-based learning curriculum improved junior doctors preparedness for "coping with uncertainty" (Bleakley and

Brennan, 2011), it is important to note though that in this case course design and assessment were focused on this specific issue. In some cases of professional development, one particular curriculum design might therefore be favorable over another as it is geared to this specific skill. Yet in other circumstances, another curriculum designed to achieve a different outcome might be superior.

Consequently, it is essential to follow a rational curriculum design that uses the overall expected learning outcomes to align the delivered curriculum accordingly. In neuroscience education, a variety of learning outcomes can be envisaged. It is, therefore, important that an appropriate curriculum design is chosen for the particular circumstances of any given course. Although inter-disciplinary teaching is considered an important aspect in furthering our understanding of the nervous system, this is not necessarily the most important aspect to consider for courses that have other outcome priorities (e.g., training of technical staff). Importantly then, the faculty needs to evaluate outcome and constantly aim to improve upon the experienced and planned curriculum (Felder and Brent, 1999). Improving the quality of neuroscience teaching, as well as the inter-disciplinary skill base of neuroscience, is required to ensure future progress in our understanding of the nervous system.

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