

Chapter 3

Theoretical Perspectives on Interdisciplinary Mathematics Education



Julian Williams and Wolff-Michael Roth

Abstract In this chapter, we develop in broad strokes the concept and history of the ‘disciplines’, a prerequisite for understanding disciplinary and interdisciplinary activity, since activity is always mediated by the cultural artefacts history leaves us. We develop the social and cultural theories of activity, practice, and discourse to offer further insights into both academic and professional ‘disciplines’, and their interrelationships, both in the academy, and in practical, joint, ‘interdisciplinary’ activity in everyday, workplace and professional life. The aim is to provide the foundations of a comprehensive theory for researchers of interdisciplinary activity. We build the analysis first of all on classical activity theory and modern developments in this tradition (a) of Vygotsky’s group and their Western interpreters, and (b) of those inspired by Bakhtin who have particularly developed multivoicedness and hybridity in dialogism. We additionally draw on Bourdieu and Foucault to consider the nature of the power structures in the disciplinary fields and discourses respectively, and how they might be resisted. We argue for a new conceptualisation of meta-disciplinary mathematics education that is a requirement of a critical mathematics education, concluding that meta-knowledge of disciplinarity is necessary for negating and becoming, to some extent, free from the discipline. We reflect on the adequacy of this theoretical battery, and its proposed synthesis for researchers in the field.

Keywords Interdisciplinary · Mathematics · Theory · CHAT · Bakhtin · Bourdieu · Foucault

J. Williams (✉)
University of Manchester, Manchester M13 9PL, UK
e-mail: julian.williams@manchester.ac.uk

W.-M. Roth
University of Victoria, Victoria, Canada
e-mail: wolffmichael.roth@gmail.com

© The Author(s) 2019
B. Doig et al. (eds.), *Interdisciplinary Mathematics Education*,
ICME-13 Monographs, https://doi.org/10.1007/978-3-030-11066-6_3

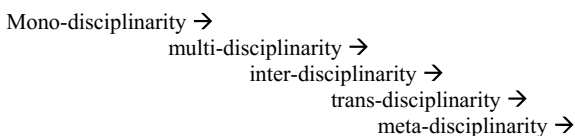
3.1 Introduction to Interdisciplinarity

The problem of interdisciplinary mathematics education requires a conceptualisation of ‘discipline’ or ‘disciplinarity’. But first, assuming an everyday, intuitive notion of discipline, we reflect on the issue of ‘inter’ disciplinarity: in fact, interdisciplinarity is often understood as a multifaceted but partially nested system of concepts, where different forms of inquiry are situated, at one or another level of complexity of the inquiry process, as follows (see a more extensive discussion of this in Williams et al., 2016) (Fig. 3.1).

Here it is suggested that ‘interdisciplinary’ mathematics involves various sorts of conjunction of mathematics with other knowledge in problem solving and inquiry. This ‘other’ knowledge is generally outside of mathematics, whether this involves one or more other disciplines (e.g. when mathematics is used as a tool within a science, geography or social sciences project) or just extra-mathematical, even ‘everyday’ knowledge (as in mathematical modelling of traffic flows perhaps, where only some everyday knowledge is needed while the mathematics might be very deep). As the relationship between mathematics and other disciplines becomes more interconnected, a genuine ‘inter’ disciplinarity emerges, when mathematics interacts with other disciplines to become something new and different (e.g. when mathematics, statistics and sociology become a new, hybrid ‘quantitative reasoning’, or in mathematical-physics, and mathematical-biology).

‘Trans-disciplinarity’ usually implies transcendence due to some sort of subsuming of the disciplines within a joint problem solving enterprise, and here the disciplines are not necessarily consciously marked, and as such, may almost seem to disappear. Essentially this is because the focus of attention is on the problem at hand, and disciplines merely provide tools for achieving a solution. In statistics, for example, the properties of distributions are of interest to mathematicians, whereas social scientists may focus on the mobilisation of the data for the purpose of comparing population characteristics. In school STEM projects, mathematics often disappears into the science and technology involved, and in fact the disappearance of mathematics quite generally in black boxes has long been noted (Williams & Wake, 2007). The fact is that when the motive of activity is to solve some real problem, some disciplines may prove irrelevant to, or even get in the way of, finding a workable or effective solution. When engaged in the process of crossing the road or overtaking a car, it may not be helpful in the moment to reflect on the kinematics involved, though some modelling of traffic may be helpful to road planners in positioning road signs and crossing facilities, or in determining speed limits.

Fig. 3.1 The spectrum of interdisciplinarity in problem solving, after Williams et al. (2016)



Finally on this spectrum, we add meta-disciplinarity, involving awareness of the nature of the discipline or disciplines involved. This becomes relevant when one becomes aware of the root disciplines—including mathematics—in their relation and difference within inquiry, e.g. when the nature of ‘using evidence’ in history and in science becomes contrasted. Thereby the epistemic qualities of the disciplines become clearer, but this is the stage at which conscious, theoretical control of the disciplines becomes possible: one can finally say, for instance, ‘this is a problem or task or situation where mathematics will likely be relevant (or not relevant)’ and even give reasons for this decision.

This kind of meta-knowledge can emerge from reflection on the relationship of mathematics or other disciplines with other knowledge at any point on the above spectrum, and so perhaps should be placed above the axis from ‘mono’ to ‘trans’. We will argue in this chapter that it prompts a new ‘cycle’ of the spectrum, where the next cycle emerges at a higher level potentially integrated with meta-knowing.

But the whole idea of the spectrum of complexity itself is perhaps incomplete, as it is not quite clear how an academic ‘discipline’ and ‘other knowledge’ should be understood: we will revisit this spectrum again after exploring these notions more carefully. In our conclusion, we will argue that it may be desirable to think of a beyond-disciplinarity which is not only ‘meta’ in the above sense, but which we will term ‘knowingly un-disciplined’, i.e. to some extent freed from the disciplines that bind problem-solving and inquiry to disciplinary norms and their limits (Williams, 2016).

3.2 Professional Disciplines

But now we come to the notion of ‘disciplinarity’ in the professional sense, in the world outside of academic ‘sciences’ proper: for instance, we may speak of multi-disciplinary teams in and around the health service. Here the disciplines may appear superficially in different job titles and remits, such as nurse, teacher, general practitioner, and social worker, but successful activity often involves effective inter-professional teamworking, often described as ‘multidisciplinary’. In the out-of-school context one sees many of the same issues arising in joint work as one does with interdisciplinary work in academe and science: but now team work, professional or disciplinary ‘identity’, and division of labour are absolutely essential and must somehow be subsumed in the holistic interest of the motive, e.g. the ‘health of the patient’. Thereby, each professional ‘discipline’ then has some sort of professional identity at stake, but must also prove itself as efficacious to the larger good, in the ‘joint enterprise’ or activity. Each discipline, even to justify itself, has to allow itself to be subsumed into an integrative whole, which has its own dynamic that is likely to differ from the dynamic of each contributing discipline. When more than one profession is involved, then some practical awareness of the possibilities for relations between the professions is required, which Wenger (1998) calls ‘knowledgeability’ in the landscape of communities of practice, and which Edwards (2017) has called

‘common knowledge’ that gives rise to relational expertise and hence ‘relational agency’. The point here is that teamwork involving distinct disciplines demands of professionals not just that agents know about the other teamworkers’ disciplines, but that they practise their relationships collaboratively with other disciplines in effective ways in the interest of their shared aim or objective (Edwards, 2017).

In addition, professional disciplines also often have their scholarly academic and practical ‘knowledge bases’—though their professionalism may be defined more often by the practical competences and membership of a professional association than by their formal academic accreditation or disciplinary qualification as such. Indeed many of these professional disciplines have spawned specialist schools in academia, as they demand academic qualifications and accreditation as a minimum for entry to their profession: schools of engineering, medicine, and now nursing, social work, and even film, computer games and so on are or are becoming commonplace in universities. Indeed, some have been present from the foundations of many, even the medieval, universities (e.g. theology, medicine, and teaching). In the next sections then we seek to illuminate both *academic* and *professional* disciplines in a general theory or conceptual framework of disciplinarity, within a historical, social context.

3.3 Disciplinarity in Sociocultural Activity Theory

The journey over the terrain of interdisciplinarity must begin by seeking to understand why disciplines in our general sense arose and continue to flourish, even producing new sub- or hybrid-disciplines. We need to see how they work both separately and together to service social functions. Only then can we understand the difficulties and constraints—but also the opportunities—that interdisciplinary work poses.

Disciplinarity is both (a) a social phenomenon caused by increasing specialisation and differentiation of labour involving social, material and discursive practices, and (b) a form of discourse making the specialisation ‘thematic’ (located in a coherent body of transmittable or ‘teachable’ knowledge). Although this division of labour preceded the birth of formal teaching, these two aspects of disciplinarity have become mutually reinforcing. The term itself derives from the Latin *disciplina*, meaning teaching, instruction, training, branch of study, philosophical school, monastic rule, and chastisement. By Chaucer’s time ‘discipline’ was used to refer to branches of knowledge, especially to medicine, law, and theology, the ‘higher faculties’ of the university. In the sociology of knowledge, the origin of science has been situated in the religious forms of life, with associated rites, bodily discipline, and asceticism; modern science, which in certain respects negated religion, nevertheless is characterised by rules and norms derived from the religious practices and discourses it largely has replaced (and as such harbours gender, racial, and class historicity).

In any sociological account, disciplinarity is treated as a social phenomenon. The smallest unit of analysis for any *specifically human* social phenomenon has to be one that has the key characteristics of society we wish to analyse. One such unit is ‘productive labour activity’, involving the production of things for consumption,

i.e. meeting human needs. Productive activity engaging with a particular, distinctive, material and discursive practice, together with its consumable products, can be seen as defining the functions of any discipline, and is the means to understand a discipline’s abiding meaning and structure. Thus, the discipline of mathematics or medicine should be understood in its functionality, whether in producing effective transport or healthy humans.

In this view, disciplinarity did not exist from the beginning of humankind, but came into being as ‘disciplined activity’, to meet some specialised need. The many different forms of production that exist today historically have emerged as a result of increasing division of labour and specialisation, making production more efficient or its products more effective (or meeting new, anticipated needs). But in some specialties an infrastructure of knowledge requirements grew, such that teaching in some form became functional and even necessary: and this teaching begins to characterise the specialised activity of an emerging discipline. The old-timers in a profession become the teachers, and their nurturing of a body of knowledge becomes a key component in the production and reproduction of the discipline. This nurturing of knowledge through teaching, when it becomes formalised in a curriculum and school, becomes disciplinary activity of a different kind from the specialised activity that gave birth to it, and typically becomes alienated from productive labour as such in academies and schools. In previous work, for instance, we pointed out how (and why) the practice of graphing takes quite distinct forms in schools and workplaces. This is because of the way assessment shapes school activity, which must have the appearance of equity (Williams, Wake, & Boreham, 2001; Williams & Wake, 2007).

Any productive activity generally involves collective, joint labour. It may be characterised by a unity of a number of moments, including the *subject(s)* dialectically engaged with the *object (or ‘object-motive’)* of activity. This dialectic is significantly mediated by the whole historically evolved, social and material system of production, involving means of production such as tools and signs, but also conventions, and the division of labour between subjects governed by rules and regulations, see Engeström’s schema (1987) adapted in Fig. 3.2.

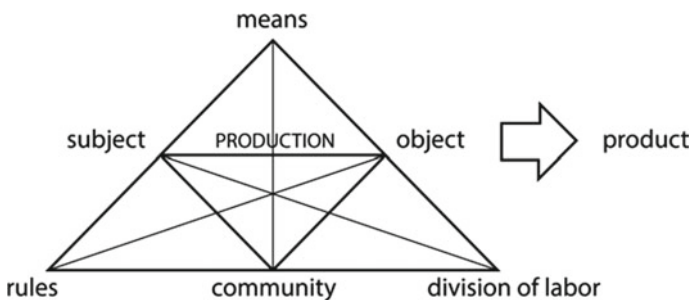


Fig. 3.2 Cultural-historical activity theoretic schema of an activity system. From Engeström (1987), after Leontiev (1978, 1981)

Leontiev exemplified his concept of ‘activity system’ (defined as the whole ‘ensemble of social relations’ as Marx put it) in the case of the pre-historic primal, collective hunt. The hunter(s) are subject(s) jointly engaged in hunting the game (the material ‘object’ of the hunt) in order to meet their needs (consumable food, feathers/fur for making clothes, etc.)—thus the hunting activity engages a community in transforming its object (the free, live animal) into a serviceable outcome (food, clothing). The ‘motive’ of the hunt is precisely this envisaged outcome and Leontiev says this ‘object-motive’ is what defines the activity as such, and what makes it functional for the community. The hunt as an ‘activity’ is collective, but is constituted by a number of coordinated, observable individual goal-driven ‘actions’ (the tracking or frightening of the prey into the open, the transport back to camp, the preparation, cooking, and feasting) mediated by certain tools (weapons, beaters) signs (calls, speech) and norms (who does what and how—the killing, cooking, sharing). There may be a division of labour, with some flushing the game out of their nests/hides while others prepare for the kill. The rules of the community may indicate that certain roles in the hunt have prestige, command special value and so on, but in primitive societies the division of labour is generally rudimentary, and in comparison to modern labour the whole activity and its object is relatively visible and maybe conscious.

In complex modern labour activity, often the activity as a whole is not so visible, and one only becomes conscious of it through reflection or analysis, even when one is aware of one’s own role and actions that are part of the whole enterprise. Leontiev expressed interest in the moment when one becomes conscious of the motive of the activity as a whole (e.g. why we should study history) or of the operational level and the functioning of tools in our actions (as in breakdown moments when one becomes aware of the significance of mediating tools like computers or signs like language).

In understanding the functionality of a discipline like mathematics in productive activity then one may see it in the conceptual instruments (or even embedded in the physical instruments such as diagrams or measurement tools) that afford productive activity *with* the discipline (it is only in mathematics per se that the mathematics itself becomes the object of the activity). But this then is reflected in all the other moments: the subjectivity of the subject, who might be disposed (or not) to use mathematical means and instruments; their relation to other subjects involved in the activity who might be mathematicians or other specialists; the community or communities involved in the production, or those who might be called upon to engage in some specialised way, and so on. Thus to understand mathematics as a discipline one must understand its function in, and as, labour activity, and in any of the moments of the activity system (Fig. 3.3).

In Leontiev’s account, the directedness of activity correlates with affect (emotions), which constitutes a form of consciousness about the current status of the activity and the satisfaction of a need that may arise from the outcome. Whereas in early human activity, the meat was used to satisfy the dietary needs of the hunting party, the fulfilment of a need may be less apparent in modern productive activities, where workers sell their labour for a wage that is used to satisfy a diversity of needs (housing, food, clothing, or leisure). This translates in learning and education to

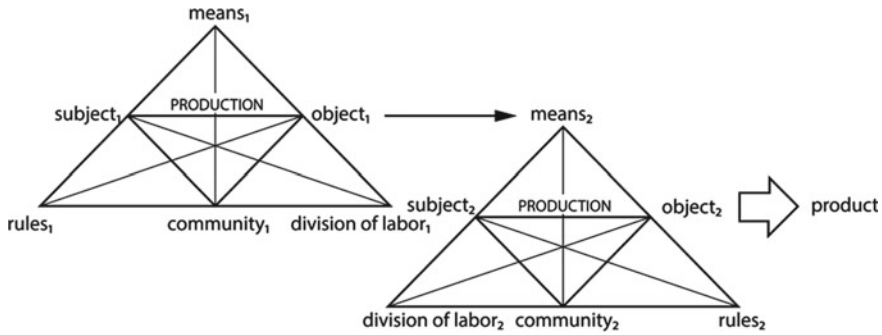


Fig. 3.3 In this arrangement of activity systems, the first activity system has as object/motive the tools required in the second activity system (e.g. industry making the weapons but the military applies it to wage war)

learning outcomes, grades and accreditation needed for progression, social acceptability/respectability, or even a career. Because an activity is a whole unit, every action contributing to its accomplishment also is permeated with this affect.

The triangular schema for cultural historical activity theory (Fig. 3.2) has its weaknesses—as any simple model must. In particular it misses an important element in Leontiev’s account of an activity system, in that it fails to distinguish between the individual subject’s conscious goal and the social motive of the collective activity as a whole. Another weakness is the static representation of the schema: Leontiev conceived of the activity from the beginning to the end as a whole unit so that every part (subject, object, etc.) is changing *within* this unit. This springs from the problem of schematically representing a dialectic in a diagram, and dialectical relations with line segments. Thus, the subject-object relation should be understood as a dialectical one in which both are moments of change and development, in which each is mediated by the other; so, the object in its current state and the ‘ideal’ image of the final product together form the object-motive of the activity. Thus, for example, a builder has all materials and tools at hand and the ‘ideal’ image of the finished house. The object is both the raw material being transformed into a product, but also, in its ‘ideal’ form, is the motive, i.e. the envisaged outcome of the acting subject. Similarly, the subject is being transformed through activity (one may call this learning, or in some cases development), reflecting their developing actions on the object and relations with other subjects engaged in joint activity.

‘Disciplined’ mathematical activity may thus be of two very different kinds, according to whether mathematics is only the instrument of labour or also its object—(e.g. for creating new mathematical knowledge). First, an activity may involve labour that benefits from a particular discipline, such as when the performance of a task whose object (e.g. costing a project) benefits from some mathematical disciplined knowledge and actions. Second, activity may have mathematics as the object of activity itself, such as when a theorem is to be proved, or a technique learned. In the first case the mathematics may be instrumental, providing tools for

the actions but not their object; while in the second case the object and its product may be mathematics (and the instruments may also be mathematical).

Most importantly for learning, subjects' activity also is dialectically both motivated by, and causative of, the subjects' *consciousness* and *personality* (Leontiev, 1978). In 'disciplined' activity, subjects engage with each other in joint work which obeys disciplinary rules, and thereby transform themselves into disciplined subjects, who may learn and even develop disciplined personalities and identities. An important aspect of the learning of subjects in activity is the contradictory forms of awareness and subjectivities of those involved: thus a subject engaging in joint activity may be confronted by new understandings, practices, and motives, leading to development of consciousness and personality (by 'personality' Leontiev means the structure of one's whole being or life-activity, including the person's character and disposition to engage in certain activities and systems).

Finally, it is impossible to understand the relationship between discipline and institutions if we fail to acknowledge their basis in productive activity and its historically produced mediating conditions, which explain power relations and oppression for instance (Bourdieu, 2000). However, we need to go further in this analysis, contemplating what is involved in the work of the discipline (i.e. its learning and teaching) and how this relates to the productive capacity and thus to the production system outlined above. In the next section we introduce the separation or alienation of the discipline from productive labour as such historically.

3.4 History of the Disciplinary Nature of Human Praxis

Understanding the cultural historical legacy that is entailed in our 'disciplines' may help us to understand the nature of the disciplines themselves. But it also may help us understand why inter-disciplinary work can be difficult, confronting certain sorts of obstacles, power structures, and questions of identity, and differences in understandings of knowledge, discourse and practice.

In classical sociological approaches in the Eurocentric tradition, formal notions of discipline and formal aggregations around particular practices are said to have emerged at the beginning of the Middle Ages, but their Western origin dates back at least to ancient Greece with the emergence of industries besides agriculture (Durkheim, 1893), involving inter-city, inter-state and even international divisions of labour and trade. Discipline as such requires a form of corporation in an institutional form for an aggregate of people, but this institutional form does not in itself constitute a discipline. During the Roman Empire, the different trades came to be treated as entities with particular functions in the public service, the charge and responsibility for which lay with the corporation. Because the service was imposed, requiring state sanctions to maintain it, the corporations ceased to exist with the end of the empire. In the European context, they were reborn in virtually all societies during the 11th and 12th centuries, when tradespeople felt the need to unite, forming the first confraternities.

The confraternities and the guilds they gave rise to, as authorities regulating the practices of their members ('rules' in Fig. 3.2), can be seen as the first organisational structures that exert themselves as forces on the formation of the durable dispositions of its members. Such regulation occurs 'through all the constraints and disciplines that [the organisational structure] imposes uniformly on all agents' (Bourdieu, 2000, p. 175). In the European context, the training of traditional artisans began with *apprenticeship*, which ended when aspiring individuals became *journeymen* upon successful completion of a specific piece of work in and with which they exhibited specific skills. As journeymen, they travelled and worked in different locales until ready to complete a 'Meisterstück' [literally a *masterpiece*, a piece of work to qualify as a master craftsman] to be judged by members of the guild. Through the piece of work, journeymen exhibited mastery of the means of production (Fig. 3.2) and the form of consciousness required for the transformation of objects into a craft-specific product. If successful, they became *master craftsman* and obtained the right to have their own shop, train apprentices, and employ journeymen. The old forms of reproduction were reborn in the division of training and work, cross cut by another division of theory and praxis: the former occurring in (vocational) school and college, the latter as practical apprenticeship or experiential learning. Even the designation of 'masters' found a new life in the 'Masters degree', and the trade certificates mutated into high school and college/university diplomas.

The increasing division of labour partially is the result of the increasingly specialised knowledge required to do a particular job. 'The production of ideas, of conceptions, of consciousness, is at first directly interwoven with the material activity and the material intercourse of men (sic)—the language of real life' (Marx & Engels, 1974, p. 47). This same progressive division of labour also split theory and practice, the former often being taught in schools, the latter on the job. Indeed, 'division of labour only becomes truly such from the moment when a division of material and mental labour appears' (p. 51).

In the history of intellectual (theoretical) disciplines, 'the specificity of the scientific field stems from the fact that the competitors agree on the principles of verification of conformity to the "real", common methods for validating theses and hypotheses' (Bourdieu, 2000, p. 113). Numerous case studies show how new disciplines or non-disciplinary fields—penology, education, nursing, midwifery, biology, or psychiatry—are tied to: specific, shared discourses and practices; economies of concepts; supporting institutions; conditions and procedures of (social) inclusion and exclusion; transmission and training; relations to law, labour, and morality; and (disciplinary) practices or technologies of surveillance, government, and control (Foucault, 1970, 1978, 1988).

Foucault's archaeological, genealogical and critical studies also reveal who controls existing discourses and how these constitute the very boundaries of any new discipline. As a result, a focus on 'disciplinary boundaries' rather than 'discipline' can help reveal an understanding of the phenomenon as a combination of internal and external social processes. These boundaries are revealed (a) in the relations between distinct disciplines, and (b) in the relation between disciplinary practices and labour activity in which disciplinarity is subsumed.

The academic, scholastic disciplines have their Western origin in the medieval divisions of the trivium (grammar, rhetoric, logic) and quadrivium (arithmetic, geometry, astronomy, music) that lasted to early modernity (d'Ambrosio, 1990). The sciences originated in philosophy, 'which fragmented itself into a multitude of special disciplines of which each has its object, its method, its mind' (Durkheim, 1893, p. 2). The objects of inquiry and the principles on which they are based historically were re-ordered towards the end of the 18th century and the arrival of mathematisation. Before Kant's critique of reason, representations were inherently linked. With *mathesis*—i.e. the systematising practices establishing the order of things—an epistemological differentiation occurred, according to archaeological and genealogical analyses, into a field of 'a priori sciences, pure formal sciences, deductive sciences based on logic and mathematics' and a field of 'a posteriori sciences, empirical sciences, which employ the deductive forms only in fragments and in strictly localised regions' (Foucault, 1970, p. 245).

In sum, a discipline functions as 'a system of control in the production of *discourse*, fixing its limits through the action of an identity taking the form of a permanent reactivation of the rules' (Foucault, 1972, p. 224). One cannot speak 'the truth' outside of such a system, as can be seen in the case of 19th century biology, where the statements of Gregor Mendel about heredity made no sense to contemporaries. It was only after a complete shift in the disciplinary discourse of biology itself that Mendel's statements, its objects and discourse, were recognised as true. That is, one can 'only be in the true ... if one obeyed the rules of some discursive "policy" which would have to be reactivated every time one spoke' (p. 224). In this analysis, (disciplinary) forms of discourse, though also an opportunity, first of all need to be thought of as constraint. This constraint arises in part from the acceptable forms of representations and the associated practices that both constitute and distinguish the discipline and its boundaries (e.g. see Lynch, 1985).

3.5 Physical and Mental Discipline: Forms of Thought and Practice

From the definition of *discipline*, it is apparent that the term constitutes a double-edged sword: (a) it specifies the organised ways in which scientists and practitioners go about their work such that they can indeed be identified in terms of specific practices; and (b) getting to the point of exhibiting these practices requires physical and mental discipline, generally instilled by imposing (more or less severe) constraints in the way people work. In fact in Foucault's genealogy, discipline arises historically through punishment, and emerges as a technology of power through surveillance that is increasingly internalised as self-surveillance. Arguably then, we are first disciplined by others before increasingly disciplining ourselves.

If we return to Fig. 3.2, but now consider the relation of the two alienated and separate activities of 'maintaining the discipline through teaching', and 'labour activity

mediated by the discipline' then we see (in Fig. 3.3) some sources of new contradictions. Thus, the consciousness associated with learning actions (e.g. learning to read instruments) is now envisaged as providing instruments of productive labour (using instruments as tools to make consumables, say). However, there is plenty of room for things to go wrong here: typically the learning outcomes are not in fact fit for purpose, and the learners know it. Then an 'alienated' discipline is required to motivate the learning activity itself: institutions of learning become increasingly empowered to create and assert new motives for the learning of disciplinary knowledge.

Even military discipline, the epitome of discipline and its historical antecedent, was the result of increasing power through coordinated actions, involving physical, material, and behavioural standardisation of rigorous, detailed procedures—a model for schooling book-keepers and perhaps school mathematics. These disciplinary forms also achieve cohesion and esprit de corps, and thus implicate certain kinds of authoritarian disciplinary identities. The emergence of discipline in the military precedes but subsequently develops alongside schooling in the monastic tradition, and finally military schools emerged alongside formal, mass schooling, which constituted not only physical and mental discipline but also a system of social ordering (Foucault, 1978). For Foucault, discipline involves primarily a technology of control over the body, a 'microphysics' of power, which results in the docility of those so disciplined. Strict adherence to specified rules and linguistic forms subsequently constitute a self-imposed discipline.

The significant point here is that the practices involved in maintaining the discipline (its teaching and learning) become at least somewhat separated or even alienated from the activity systems where they are supposed to be practised productively. The disciplines take on a life of their own. This reached its ultimate form in mathematics, when pure mathematicians like Hardy declared the absolute lack of utility of their pure mathematics. And yet, there is hardly a branch of pure mathematics that might not turn out to be importantly useful, even though in some cases this may be some generations after the discipline has invented it. This has proved repeatedly the case now for some hundreds of years, from Boolean algebra and its eventual exploitation in digital technologies, to non-Euclidean geometries and modern Physics.

It has to be claimed, then, that the disciplining of mathematics that takes place by mathematical research communities is not reducible to an arbitrary discipline like that of the military. Its disciplinary criteria of certain habits of mind—elegance, proof and efficiency—appear to serve the discipline well in some functional sense, even though it can be argued that these have become independent of any immediate utilitarian, productive activity outside of mathematics itself. How has this happened, and how can one ensure that a discipline, e.g. a mathematical discipline, will continue in such a fashion? This question takes us deeper into philosophy than this chapter can go. But it is an important feature of the discipline that it continues to hold some of these properties and that this property may not apply equally well to other candidates for the title of discipline.

There is a strong case for questioning 'mathematics education' as such a functional discipline; many including ourselves have argued that our discipline has become so detached from mathematics proper as to be dysfunctional. This may be true of many

other school subjects as well, and we should not reduce the value of interdisciplinarity of mathematics with other disciplines to that of the managerial integration of school subjects, even those that bear the same name!

3.6 Interdisciplinarity: Working Between and Across Disciplines

The problem of interdisciplinarity may be framed in terms of the activity theoretic approach outlined above. Here, paradigmatically, in contrast to the normal organisation in society, whereby products are exchanged by means of a generalized exchange form, i.e. money, two or more groups (organisations) representing different disciplines, may come together to work on a common object to result in a common product (Fig. 3.4). Thus, for example, one study reported how an interdisciplinary project emerged when three ‘relatively autonomous project groups, composed of researchers with different disciplinary backgrounds’ came together for the purposes of constructing ‘the key parts of this projected production system: the development of microbial strains’ (Miettinen, 1998, p. 430).

Here, readers should keep in mind that an activity is defined by the object/motive on which the collective is working, but the object is—like all the ‘moments’ represented as nodes in Figs. 3.2, 3.3 and 3.4—in the process of transformation: the work of the collective involves transforming the ‘raw’ objects into ‘outcome’ objects that meet a social need. In the classical case of labour activity, the actions of the various workers lead to the manufacture of finished consumables. Thus the ‘motive’ involved is the envisaged transformation of the ‘raw’ object into ‘outcome’, sometimes this motive is imagined, sometimes only emergent through the collective actions of the individual subjects involved. When we speak of ‘object/motive’ then, we have all this in mind: an activity is defined by the ‘motive’ of transforming an ‘object’ into a new form, an ‘outcome’ that meets a social need: that is, it has some kind of use value (which in the classic case of commodity production is the ‘use value’ of the commodity in the sense of Marx).

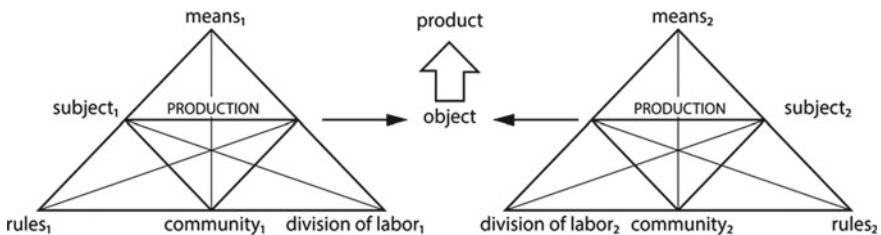


Fig. 3.4 In an interdisciplinary project, two different and otherwise autonomous activity systems collaborate with a *common* but temporary object/motive

Common object-motives often characterise interdisciplinary projects, even though the contributing disciplinary activity systems differ, each with its own distinctive characteristics, tools, and perspectives (Fig. 3.4); other forms of collaborations across disciplines may be organised differently, e.g. as in Fig. 3.3. The possible contradiction is immediately apparent. Because each part of an activity system is a function of the whole and is permeated by the characteristics of all other parts, the motives characterising any two activity systems may differ. That is, any interdisciplinary endeavour involves the work of specifying a *common* object/motive (product), which likely differs from object-motive1 and object-motive2 that characterise the respective mono-disciplinary practices (Fig. 3.4).

In the case that the two disciplines involved *are* able to come together in joint work on a common object, then it is possible to analyse their joint activity as a single activity system with a division of labour that incorporates both disciplines. In the simple case of joint work of a doctor and patient, the two may work seamlessly to prescribe and effect the treatment with a common object/motive of fixing the patient's medical problem; but the whole may fall apart into separate and contradictory activities if their motives are not well aligned, perhaps because the patient has other motives than their own health, they dislike the side effects of the treatment, or the drugs are too expensive, etc. In the education context the disjuncture may be even more strongly marked, as there is in general not much negotiation between the teacher and the learner as to the object of their joint actions: indeed it is disastrously common for the teacher to conceive of the object as *being* the learner. Another general problem in the education context is the misrecognition of the true object/motive. Thus, it is often stated that learning is the object of schooling, whereas in practice, the production of grades, grade reports, and diplomas is the actually realised motive toward which schools, teachers, students, and parents are oriented (Roth & McGinn, 1998).

A common case in point in education is the misalignment of the teacher who designed a classroom lesson and the teaching assistant who is assigned to help a group (usually a particular child or subgroup of the class): unless the teacher and assistant share understandings of the purpose of the lesson there may be essentially separate activities going on even in the mono-disciplinary classroom. (Even more sharp might be the case of the separation of the curriculum designer/author from those who teach, e.g. the teacher who uses a powerpoint designed by some other teacher with a different perspective!) Interdisciplinary teaching is even more prone to this, because the teachers of different disciplines have distinct disciplinary practices and learning outcomes in view.

The difficulty in defining a common object can often explain the failure of projects designed to be interdisciplinary. On the other hand, in successful projects, new object/motives may be created in such a way that they make sense within each of the disciplines (e.g. Miettinen, 1998). A good example of such an endeavour was observed in the collaboration of printers and designers to redesign the printers' workplace (Ehn & Kyng, 1991). Together, representatives from the two disciplines built mock-ups to model what happens in the workplace, and, in so doing, developed a new form of discourse that made sense within each discipline and constituted a sense-giving field that made sense across the fields.

One function of common objects (e.g. representational tools) is that they coordinate the activities involved even though the practices surrounding these objects differ. These objects are commonly known as *boundary objects*: such objects define boundaries between practices (forms of activities). Thus, for example, in the manufacture of an aircraft, many different disciplines are involved; the coordination between these very different disciplinary fields is achieved by means of drawings (Henderson, 1991). These drawings have different functions and are understood differently on the shop floor, in the accounting department, for the electrical engineers, or the inventory control department. Because of this, the object also may be thought of as a *conscriptio device*, that is, an entity that brings together (enrols) members of different disciplines (communities of practice) for the purpose of realising a common object/motive, which also is itself made visible by that same device.

There may also be (usually small numbers of) individuals who are familiar with and exhibit expertise in two disciplinary fields (Star, 1995). They cross and transcend boundaries, sometimes being called ‘brokers’, ‘wizards’ or ‘gurus’ that are highly competent in multiple domains and across multiple systems of formal representations. More prosaically, we are all multi-disciplinary in the loosest senses of ‘discipline’: we taxi-drive our children to school, become launderers on wash day, paint the garden fence on the weekend, nurse our old-aged when sick, etc. But these are riven with contradictions and power relations: some are paid, some confer esteem and cultural capital, and all are shot through with social divisions along the gender, race and class divides.

3.7 Interdisciplinary Power and Conflict

Anyone working in academia knows about the institutional hierarchies between and within faculties and forms of knowledge. Thus, the natural (‘hard’) sciences tend to be regarded as higher in esteem and more powerful than the social (‘soft’) sciences (Bourdieu, 2000); within a particular field, the same gradations are reproduced, e.g. in psychology, there are gradations from the ‘hard’ (e.g. experimental psychology in the lab) to ‘soft’ (counselling psychology); and within each field there are gradations, where some scholars are on top of the heap and others are the new underclass of ‘proletarianised intellectual’ on zero hours contracts. The disciplinary divisions between hard and soft sciences found a parallel in gender divisions, which was the result of institutional practices that systematically excluded women from the natural sciences, especially hard, natural sciences (Shumway & Messer-Davidow, 1991). Similar power differences have been recognised within multi-disciplinary teams in inter-professional contexts (e.g. between medical doctors, nurses, and assistants for instance).

One of the conditions for interdisciplinarity to function effectively is the active management of the historically developed attitudes between disciplines and forms of inquiry for the purpose of overcoming condescending and colonising attitudes (often amplified by racism, sexism, class etc.). The structures of power gradations that

separate the faculties and disciplines—while they have a degree of autonomy—are homologous with the entire field of power in society at large: natural sciences (STEM) being opposed to faculties of social sciences (Bourdieu, 1984). The ruling relations within disciplines reproduce those between faculties. Knowledge constitutes a form of ‘symbolic capital’ that may be accumulated as any other form of capital. In the sociology of symbolic capital, the university faculties are characterised by their position within the historically evolved academic field of power, each with its own internal field of power and cultural capital. Within disciplines, certain schools, sometimes associated with specific universities (e.g. Ivy League or Oxbridge) reproduce these structures through patronage and graduate student exchange (e.g. Traweek, 1988).

The practices of selection and indoctrination *within* each discipline contribute to the reproduction of differentiation *between* the disciplines. Cultural capital contributes to the constitution of a discipline within society as a whole and to the relative status of the individual within the discipline. This entire disciplinary formation therefore acts as a great ‘weight of the world’, making for difficulty in expecting those ‘schooled’ and ‘disciplined’ in one field to relate in effective ways with others whose habits have been formed in relatively independent, and contradictory fields. Thus alienation of the discipline from productive labour provides the conditions for strengthening the alienation between disciplines, producing the conditions for ever greater barriers to interdisciplinary work in the academy/school.

3.8 Transdisciplinarity: Considerations of Dialogism, Heteroglossia, and Voice

In everyday life and in most productive work activity, one is rarely conscious of the multiple disciplines that have played a part historically in the concepts, tools and objects that we engage with. Getting on with the task, we ignore the mathematical work that went into the design and manufacture of the tools we use (the computer), the rules of the systems we unconsciously obey (the timetable), even the mathematical concepts embedded in the discourses that mediate our work (there isn’t enough time to list them all). In getting on with life, then, we transcend the disciplines, and our activity is transdisciplinary in the sense that we are not conscious of the disciplinary moments of the activity that are hidden in black boxes. But if we look closely and reflect, we can begin to see the many disciplines mediating our work and discourse, and a heteroglossia of such disciplines in everyday transdisciplinarity. The idea of heteroglossia is well exemplified in the preceding example of the printers and designers, who began the interdisciplinary project by developing a hybrid discourse in which *that* workplace redesign was accomplished (functioning much like *Sapir*, the hybrid language of Mediterranean merchants permitting trade across nations, cultures, and mono-languages). Otherwise, the two activity systems remained distinct and maintained their disciplinary discourses.

To add to the previous account, then, one should consider Bakhtin's conceptualisations of voice, dialogism, and heteroglossia: many in activity theory consider these Bakhtinian concepts to be part of the modern version of cultural- historical activity theory. Given Bakhtin's view of the social world, we can consider a 'discipline' as a language genre—or, equivalently, a Wittgensteinian *language-game*, defined as a language and the practical activity with which it is interwoven—in which certain structures of utterance are formed with particular functions and audiences in mind: there is a natural assumption that persons in modern cultures speak with many voices, adopting many such genres as appropriate, within a polyphony of discourses. In this view we can all perhaps be expected to be multivoiced, or multidisciplinary in a discursive sense.

We can now draw on Bakhtin's conceptual tools: in Bakhtin's framework an author's power is 'monologic' when it demands that the addressee adopts the voice and genre of the speaker, and when the addressee is thereby ventriloquated by the authority (Bakhtin, 1981). On the other hand in ethical, 'free', but effective communication, there should be a dialogism between speaker and addressed, in which the speaker seeks to offer the addressee language that can become 'internally persuasive'. In this view, effective multidisciplinary communication would require speakers to at least partially adopt voices in the language/discipline of the 'other' for others who 'speak' a different discipline's discourse, or for instance, a different genre of mathematics (Williams & Wake, 2007). In Wenger's (1998) conception of 'knowledgeability' within a landscape of communities of practice, to be effective does not require one to be an old-timer or competent practitioner of adjacent boundary communities but one needs to be just knowledgeable enough of the practice to be effectively competent with one's own. In the school context, this means that the teacher needs to understand the classroom to some degree from the perspective of the teaching assistant, and vice versa, even though these two professionals may be considered to belong to different professional communities/disciplines and prefer different language genres.

Together with Bakhtin's concepts, this more positive and hopeful conceptual framework might have affordances that will support understandings of multidisciplinary using ideas of the broader 'social language' in which distinct language genres are formulated, and make use of his notion of dialogism to think about talk across disciplines (where one's word is always half the other's, i.e. 'someone else's') and even 'hybridity' of disciplines. A hybrid utterance according to Bakhtin contains at least two interanimating voices in ways that allow new meanings—this can occur in dialogues in ways that produce creativity, and novelty—typified in his analyses of humour. This exemplifies the hybrid utterance, because the hybridity occurs at the level of meaning of the utterance; but still one can discern the two separate voices and language genres within the utterance. This does not involve, arguably, a new 'hybrid language or language genre' such as that which might occur when two disciplines create a new one, such as, perhaps 'biochemistry', or even 'engineering-mathematics'. We suggest however that what occurs when specialist mathematicians or scientists collaborate across disciplinary boundaries in some task might be usefully examined from this perspective. The key point is that each discipline does not need

to incorporate the expertise of the ‘other’, but to have just enough meta-disciplinary knowledge about the nature of its own discipline in its relation to the other disciplines and to the task to engage in an effective dialogue (i.e. one where the object can be adequately formulated by both disciplines). This is just what is required to speak in hybrid utterances that include the other disciplines, at least where the object of activity is concerned, without necessarily forming a new hybrid discipline.

In the account of interdisciplinarity given above, we call this metadisciplinary knowledge, and the suggestion in the Bakhtinian frame is that this might best be studied (and developed) in a transdisciplinary context of activity where each discipline rubs up against and is subsumed within a wider activity, possibly with other disciplines also. What determines whether the two disciplines are engaged in the *same* activity, ultimately, is that they share a common object-motive, even when they maintain their own disciplinary tools, within a division of labour that includes both disciplines. This requires enough meta-knowledge to negotiate their motives with ‘others’, which includes understanding what each discipline can offer.

3.9 Identities in Disciplinary and Interdisciplinary Practices

The focus on identity in much social theory might similarly be significant in many inquiries, particularly those that are interested in learner engagement, choice-making in further and higher education, and career choices (i.e. learner identities) but also professional identities (e.g. teachers, educators, health professionals). The consequences of learning to see oneself through reflective activity as a ‘certain kind of person’ (perhaps a scientist or mathematician of a certain kind) are thought to be crucial here: but these reflections are always reflections ‘on’ past experiences, and particularly how ‘others’ have positioned oneself in joint activities. Thus we have been told by professors of mathematics in prestigious universities that ‘most of them (i.e. their undergraduate mathematics major students) won’t become mathematicians’, positioning their graduating students as non-mathematicians even though they are likely to be employed as future teachers of mathematics, users of quantitative methods in industry, etc. In this regard then, we consider the need for a social theory of identity-making in practices of various kinds, including in dialogues with powerful others who position subjects in activity, as well as reflective discourses with oneself. Clearly disciplinarity and interdisciplinarity mediate these: and whether an engineer or a scientist sees themselves as some kind of mathematician might be a key question to ask when mathematics is but one discipline in an interdisciplinary or transdisciplinary endeavour. Compared with professional identities, and post-compulsory students’ learner identities, school students tend to have relatively weak attachments to the disciplines. It is then more important to many that the disciplines be shown to be of some use, than that they become inducted in the practices of the discipline per se.

Consider the example of an interdisciplinary mathematics, science and technology project in a secondary school engaging the whole cohort of 150 students aged 11–12 years. In an attempt to motivate the students with an ‘outside academia’ task, the students were asked to develop a plan to improve their school environment: making their break times in school more pleasant. It was agreed that the winning project would be funded, imposing a budget of £500, to make sure the project would actually be implemented; and there was to be a vote of the whole cohort to decide on the winning project. In order to justify the timetable given over to the joint project, each subject-department led some teaching of their discipline (actually their curriculum) in ways intended to help the children consider relevant plans. There were lessons about: the science of plants and kinds of soil needed for planting; how to handle data from a survey to find out what other children would like from such a project; and regarding technology, how to design and make new furniture. Thus, each curriculum area ticked a box that the project met some of their curriculum objectives for the year, even though a great deal of the time was not spent focused on the substance of the curriculum as such.

However, of all the projects considered, the winner in the end was one that used little disciplinary knowledge, and apparently none of the science taught—much in the same way as a case described by Leontiev, which was the outcome of an inappropriately framed and chosen object/motive. The winning project involved the building of a path that would allow students to access the school directly from the public busstop, thus saving them a ten minute walk round the streets to the front entrance of the school. Transdisciplinarity appeared to win here: the students learnt important meta-disciplinary knowledge—that there may be no place for science in practice, and the benefits of an un-disciplined approach that is free to focus on the actual problem in hand. In this light, this lack of discipline can be a good thing, maybe even an essential requirement, as long as it is well informed. One has to have some knowledge about the discipline (precisely meta-disciplinary knowledge or know-how) in order to know when it may have little or no place in informing an issue. A pity there is no room in most school mathematics curricula for this.

The interdisciplinary categorisations described at the beginning of the paper suggests that transdisciplinary problem solving can, on reflection, produce meta-disciplinary knowledge that negates disciplinary power (to some extent) and introduces the expansive cycle in Fig. 3.5, where the second cycle involving the mono-inter-trans-disciplinary knowing becomes a self-aware knowing, in light of the meta-knowledge. The kind of knowledge involved in this cycle certainly includes the understanding of mathematics as ‘mathematical modelling’ for instance. But it also would include understandings of the particular historical relationship between mathematics and physical sciences or engineering; and in the case of the profession of nursing, it might involve the situated appreciation of the relationship between risk and probability, and so on.

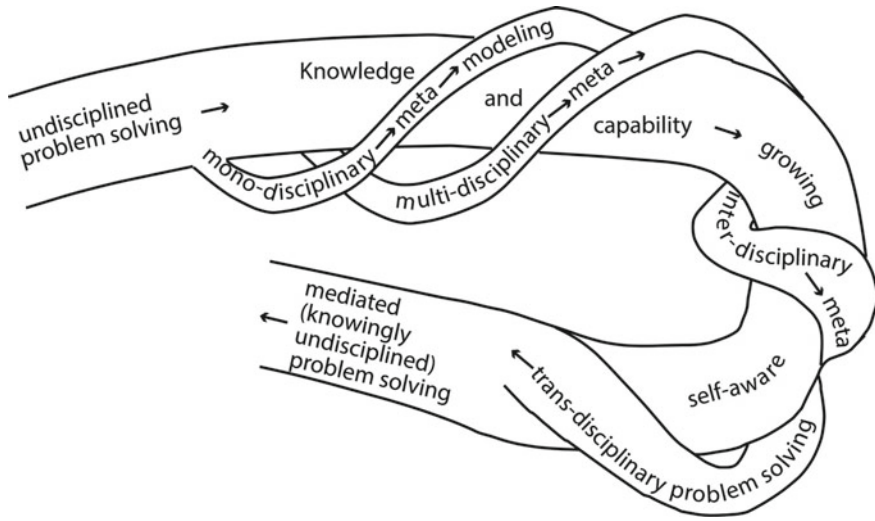


Fig. 3.5 An expansive meta-cycle of interdisciplinary problem solving

3.10 Conclusion: Social Theory for Interdisciplinarity

Activity theory (after Vygotsky/Leontiev) has given us some powerful tools to think about interdisciplinarity and the relations (contradictions) between learning disciplines and productive labour. The theory does not emphasise the structural relations with capital and power (implicating alienation) offered by the Bourdieu/Foucault perspectives, and which make salient the powerful alienation of disciplines from superseding activity, insofar as they emphasise (a) the arbitrary quality of capital (Bourdieu) and (b) governmentality of disciplines (Foucault). They also raise the possibility and shape of certain forms of resistance to capital (reflexive sociology) and disciplinary discourses (becoming aware) respectively. These two perspectives in combination might offer insights that might reveal some of the potential for interdisciplinary work but also may help explain its widely recognised failures. The concepts from Bakhtin helped to envisage a transdisciplinarity in which multi-disciplines work together ‘dialogically’, but in which the disciplines might rise to consciousness through reflective activity: hence the emergence of metadisciplinarity through transdisciplinarity. It also gives us some additional insights into activity through concepts such as language genre, mono/dialogism, and internally persuasive discourse.

Being undisciplined in the pre-historic state is a matter of absence of discipline. But proceeding historically to a disciplined culture, we can now negate this in a disciplined consciousness which is nevertheless to a degree free to be undisciplined, i.e. to one where we are aware of the disciplines (maybe even specialised and skilled in some of them) but thereby relatively un-disciplined by them. This is a new perspective on being ‘undisciplined’, i.e. being aware of making us somewhat free of disciplines.

Rather than making interdisciplinarity the new scientific dogma or ideal practice to be achieved, a more productive approach may consist in situating inquiries and endeavours according to the complexity of the questions asked. Thus, on the scale of complexity, interdisciplinarity may actually be thought of as a continuum of relations between disciplines, between mono-disciplinarity, on the one end, and trans-disciplinarity, on the other end, with multi/inter-disciplinarity and trans-disciplinarity offering more or less hybridity of the disciplines involved (Collen, 2002). As a result, neither mono-disciplinarity nor any other 'level' is ever eradicated or even invalidated; indeed the core value of the discipline may provide precisely the value to other disciplines that interdisciplinarity requires. But the continuum allows inquirers, who have the awareness, to advance by moving towards more complex inquiries involving more than one discipline in ways that lead to advances and novel forms of insights (e.g. Hicks, 1992) or to return to less complex inquiries to draw on the advantages that arise from lower levels of complexity (in objects, organisational forms, efforts).

The issue of meta-disciplinarity has hardly been explored in educational research and we suggest that this deserves a great deal more attention in the context of problem solving in general and multi-disciplinarity in particular. In this, inter-disciplinary work and education parallels the work in inter-professional work and education in contexts such as the health services, and this highlights the relation of the multi-disciplinary team to expand to include the user.

Additionally we have turned particularly to Bakhtin as a perspective on language genres to think about 'disciplines' as characterised by their disciplinary 'languages' or 'genres' and voices, but also to think of disciplines as if they actually were discourses (language-games). Then an interdisciplinary project or activity becomes metaphorically conceptualised as a hybrid utterance containing two interanimating voices, with new hybrid disciplines emerging as hybrid genres or even languages like Sapid or Creole. We suggest that this conceptualisation might be productive for future work in the field. We do argue however that the main concerns that the academy needs to address are to be found in the alienation of disciplinary activity (and thus subjectivity, identity, etc.) not only from other disciplines but also from productive labour, and specifically from 'real' inquiry and problem-solving in learners' interests. We concluded that being 'disciplined' should be challenged by the needs of labour, becoming 'undisciplined' but in a new, disciplined way, superseding disciplinary and metadisciplinary knowledge.

3.11 Coda

In a review, Williams et al. (2016) concluded that interdisciplinary mathematics education in the context of inquiry and problem solving offers mathematics to the wider world in the form of added value (e.g. in problem solving), but on the other hand also offers to mathematics the added value of the wider world. In this chapter we build on this but take the argument further and begin to emphasise the need for learners to become educated in the nature of the discipline of mathematics and of

its relation with other disciplines, freeing the problem solver to some degree to be knowledgeably un-disciplined, an essential requirement of good problem solving. In this move, theoretical resources included (a) activity theory, (b) language genres and Bakhtin, and (c) Bourdieu and Foucault.

The first involves the separation of disciplinary activities of mathematics (e.g. learning, teaching, researching the discipline itself) from their use in an expansive system of productive problem solving in practice (when the production system and other disciplines may be critical). The second involves hybridity, identity, and disciplinary discourses as language genres. The latter takes us to (field and discursive) theories of power and resistance. In all, these theoretical perspectives help us to understand how to research interdisciplinary mathematics and its cultivation in academe. But, just as we do not argue that all academic activity must be interdisciplinary, so also we do not suggest that all this theory is required for every particular task in educational research and practice. Instead, we show how these theories offer researchers and practitioners some theoretical tools, some of which, or combinations of which, can be fit for the purposes of understanding interdisciplinary activity. For instance, future research and practice will ultimately determine whether, or to what extent, and how activity can be both disciplined and undisciplined, i.e. knowingly so. We argue and conclude that one key to this knowing in the interdisciplinary context is in the expansive, meta-cycle above.

References

- Bakhtin, M. M. (1981). *The dialogic imagination: Four essays*. Austin, TX: University of Texas Press.
- Bourdieu, P. (1984). *Homo academicus*. Paris, France: Les Éditions de Minuit.
- Bourdieu, P. (2000). *Pascalian meditations*. Stanford, CA: Stanford University Press.
- Collen, A. (2002). Disciplinarity in the pursuit of knowledge. In G. Minati & E. Pessa (Eds.), *Emergence in complex, cognitive, social, and biological systems* (pp. 285–296). New York, NY: Springer.
- d'Ambrosio, U. (1990). Literacy, matheracy, and technoracy: A trivium for today. *Mathematical Thinking and Learning*, 1, 131–153.
- Durkheim, É. (1893). *De la division du travail social [Division of social labour]*. Paris: Felix Alcan.
- Edwards, A. (Ed.). (2017). *Working relationally in and across practices: A cultural-historical approach to collaboration*. Cambridge, UK: Cambridge University Press.
- Ehn, P., & Kyng, M. (1991). Cardboard computers: Mocking-it-up or hands-on the future. In J. Greenbaum & M. Kyng (Eds.), *Design at work: Cooperative design of computer systems* (pp. 169–195). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Engeström, Y. (1987). *Learning by expanding: An activity-theoretical approach to developmental research*. Helsinki: Orienta-Konsultit. <https://doi.org/10.1017/CBO9781139814744>.
- Foucault, M. (1970). *The order of things*. New York: Random House.
- Foucault, M. (1972). *Archeology of knowledge and the discourse on language*. New York: Pantheon Books.
- Foucault, M. (1978). *Discipline and punish: The birth of the prison*. New York: Vintage Books.
- Foucault, M. (1988). *Madness and civilization: A history of insanity in the age of reason*. New York: Vintage Books.

- Henderson, K. (1991). Flexible sketches and inflexible data bases: Visual communication, con-
 scription devices, and boundary objects in design engineering. *Science, Technology and Human
 Values*, 16, 448–473.
- Hicks, D. (1992). Instrumentation, interdisciplinary knowledge, and research performance in spin
 glass and superfluid helium three. *Science, Technology and Human Values*, 17, 180–204.
- Leontiev, A. N. (1978). *Activity, consciousness and personality*. Englewood Cliffs, NJ: Prentice
 Hall.
- Leontiev, A. N. (1981). *Problems of the development of mind*. Moscow: Progress.
- Lynch, M. (1985). Discipline and the material form of images. *Social Studies of Science*, 15, 37–66.
- Marx, K., & Engels, F. (1974). *The German ideology*. London: Lawrence.
- Miettinen, R. (1998). Object construction and networks in research work: The case of research on
 cellulose-degrading enzymes. *Social Studies of Science*, 28, 423–463.
- Roth, W.-M., & McGinn, M. K. (1998). >unDELETE science education:/lives/work/voices. *Journal
 of Research in Science Teaching*, 35, 399–421.
- Shumway, D. R., & Messer-Davidow, E. (1991). Disciplinarity: An introduction. *Poetics Today*, 12,
 201–225.
- Star, S. L. (1995). The politics of formal representations: Wizards, gurus, and organizational com-
 plexity. In S. L. Star (Ed.), *Ecologies of knowledge: Work and politics in science and technology*
 (pp. 88–118). Albany: State University of New York Press.
- Traweek, S. (1988). *Beamtimes and lifetimes: The world of high energy physicists*. Cambridge,
 MA: MIT Press.
- Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge: Cam-
 bridge University Press.
- Williams, J., Roth, W.-M., Swanson, D., Doig, B., Groves, S., Omuvwie, M., et al. (2016). *Interdis-
 ciplinary mathematics education: State of the art*. Cham: Springer. <https://doi.org/10.1007/978-3-319-42267-1>.
- Williams, J. S. (2016). *Becoming un-disciplined with science and mathematics*. Downloaded July
 2018 from [http://stemedcon.deakin.edu.au/wp-content/uploads/sites/25/2017/05/Proceedings-
 Julian-Williams.pdf](http://stemedcon.deakin.edu.au/wp-content/uploads/sites/25/2017/05/Proceedings-Julian-Williams.pdf).
- Williams, J. S., & Wake, G. D. (2007). Metaphors and models in translation between college and
 workplace mathematics. *Educational Studies in Mathematics*, 64(3), 345–371. <https://doi.org/10.1007/s10649-006-9040-6>.
- Williams, J. S., Wake, G. D., & Boreham, N. C. (2001). College mathematics and workplace practice:
 An activity theory perspective. *Research in Mathematics Education*, 3, 69–84.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

