

Teachers' knowledge dynamics and innovation in education – Part I.

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Teachers' knowledge is dynamic; it is constantly shaped by new information, collaboration with colleagues, engagement with teaching tools and textbooks, teaching practice in the classroom, and so on. The paper investigates how knowledge dynamics can be described, building on work conducted in the Innovative Teaching for Effective Learning (ITEL) project of the OECD. A review of literature is conducted through three analytical foci – the individual, social and socio-material – in order to explore processes underlying the dynamics of knowledge functions, structures and the emergence of knowledge. This first part of the paper looks at the individual and social perspectives. Data from the ITEL pilot study is used to illustrate some of these mechanisms. The second part will look at the socio-material perspective and, integrate the three analytical angles into a complexity view of knowledge dynamics and innovation, ultimately highlighting the different ways in which innovation in education is linked to the dynamics of professional knowledge.

Keywords: Teacher knowledge, knowledge dynamics, professional learning, innovation

Introduction

Trends in today's globalised knowledge society are greatly influencing the conditions of professional practice, learning and knowledge. A large amount of knowledge relevant for teachers' practice is generated and circulated within scientific and professional communities, as well as across institutional boundaries, resulting in a wide range of resources that partly represent conflicting evidence (Fenwick, Nerland, & Jensen, 2012). New responsibilities for practitioners include navigating these abundant resources, engaging with them, and interpreting, evaluating and applying them. In this context, teachers are also increasingly required to collaborate with others and contribute to knowledge production. Clearly, teachers' knowledge is in a constant state of transformation in this setting. Fenwick, Nerland and Jensen (2012) point to the relatively scarce evidence on the epistemic dimension of professions, in particular the dynamics of knowledge and professional expertise.

Knowledge is inherently dynamic (McInerney, 2002); it transforms as it integrates new information or evidence, is shaped through learning and experience, and is also constructed in professional practice. Understanding the complex mechanisms of these dynamics can inform the design of teacher learning, whether it is embedded in formal or non-formal teacher education (e.g. initial preparation, professional development courses, workshops), or informal settings such as work-based learning and engaging in communities of practice. Teachers do not simply acquire and develop their individual knowledge; they also produce collective knowledge that is shared in turn. These processes influence the knowledge base of the profession. Teachers' knowledge base is also affected by policy design and interventions, the success of which depends to some extent precisely on this dynamic.

Innovation and change are becoming integral to the teaching profession as a response to the complex challenges that societal changes imply (Schleicher, 2016). Innovation in education, seen as a "function of the learning

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and knowledge creation” rather than the result of research and development (Ellström, 2010, p. 27), is intimately linked to the transformation of professional knowledge. Definitions of innovation that encompass, in addition to products and processes, new ideas, beliefs, explicit and tacit knowledge are particularly helpful in education (Halász & Fazekas, 2016; Larson & Dearing, 2008). Knowledge in this sense is at the same time a driver, a main pillar and an outcome of innovation. Knowledge has been identified as a crucial factor that drives innovation because it underlies several of the incentives or “pumps” of innovation (OECD, 2004; Halász & Fazekas, 2016). It is also an outcome of innovation when new knowledge is created as a result of the innovation process. This is reflected in conceptualisations that distinguish “knowledge innovation” as a particular type (OECD/Eurostat, 2005). In fact, knowledge and method innovation was found to be present in the education sector more so than in other sectors (OECD, 2014). Creating, sharing and using knowledge are also seen as inherent and crucial mechanisms of the innovation process, for example in the Innova research project presented in this special issue. This multifaceted role is captured by the concept of knowledge dynamics.

This paper aims to review the most prominent research strands that contribute to better understanding the complex processes underlying teachers’ knowledge dynamics. The main question it investigates is: How can the dynamics of teachers’ knowledge be described and characterised? The question is addressed in two parts: Part I of the paper reviews long-established theories of knowledge and learning that have served as the basis for numerous research studies in the field of education. Associated methodologies have been evolving over several decades and have yielded different research strands, which will be discussed. Part II of the paper, to be published in the next issue, looks at more recent theories and highlights new ways of conceptualising and studying knowledge dynamics and innovation.

This paper does not intend to provide a comprehensive or systematic review of research on teachers’ knowledge and learning, rather it brings together evidence from different but interrelated disciplines, and proposes to view these through a new analytical lens: knowledge dynamics. Sources reviewed include the economics of knowledge, in particular knowledge management, the sociology of knowledge construction and diffusion, as well as educational theories. This work builds on recent theoretical and empirical research by the Centre for Educational Research and Innovation (CERI) of the OECD, which was carried out in the framework of the *Innovative Teaching for Effective Learning* (ITEL) project.

Framework of analysis

Teachers’ knowledge is produced, transferred and shaped through a variety of processes. Recent reviews tracing the development of the conceptualisation of professional knowledge and learning typically highlight three approaches to the study of behaviour, actions and interactions: the individual, social and socio-material perspectives (Mulcahy, 2012). In the individual approach the unit of analysis is the individual teacher, while the social perspective places the group, community, organisation or network in focus, in which individuals are socially embedded. The socio-material approach emphasises the embeddedness of individuals not only in social groups, but more broadly, in the material world, in which material entities (e.g. documents, objects, technology) and the way actors engage with them also become the object of analysis.

As part of the conceptual work underlying the OECD’s ITEL project, Révai and Guerriero (2017) used three analytical dimensions to study knowledge dynamics and described their complex processes from a social, a functional and a structural point of view. The first dimension focuses on social dynamics, and highlights the role of actors (teachers, researchers, teacher educators, policy-makers and so on) and their interactions in shaping

knowledge. The second dimension is concerned with the dynamics amongst the three main functions of knowledge as described in Levin's (2011) knowledge mobilisation model: production, use and mediation (or transfer). Studies related to these three main functions of knowledge focus on research knowledge, and address questions such as: How is educational research produced?; What kind of research has the potential to enhance professional practice?; How do teachers access, understand and apply knowledge? The third dimension explores dynamics of the structure of knowledge, i.e. what types of knowledge can be distinguished and how can the interplay between these be characterised. In particular, it looks at the dynamics of tacit and explicit knowledge, the process of codification (i.e. how tacit knowledge becomes explicit) and how it can facilitate access to knowledge for teachers and improve professional practice (Révai & Guerriero, 2017).

While the three above dimensions are strongly interrelated, their linkages are not completely symmetrical. The social dimension is inextricable from the other two in that both structural and functional dynamics are dependent on the behaviour, actions and interactions of the actors. Because the social processes of actors, or more generally, the agents of the educational world underlie the mechanisms of knowledge dynamics, this paper proposes to study the functional and structural aspects of dynamics along three units of analysis – using the lens of the individual, social and socio-material approaches –, rather than analysing social processes as a separate dimension.

The framework proposed for the analysis (see Table 1) looks into three questions. First, what happens to knowledge – that is, what are the dynamics of its functions in terms of the interplay of its production or construction and use, and how is it mediated, shared and brokered? Second, what is the interplay between different knowledge types – i.e. what are the dynamics of the structure of knowledge? And third, in what ways are knowledge dynamics and innovation linked? The analysis corresponds to different conceptualisations of knowledge and learning that are distinguished based on their main focus of investigation. Using various examples, this first part of the paper illustrates how the individual and social perspectives describe functional and structural processes differently. The second part will demonstrate how the socio-material view explores the emergence of knowledge, and propose an integrated approach via complexity theory, which is able to bring the different foci together under a broad systemic view.

Focus of Analysis	Dynamics of Functions: What happens to knowledge?	Dynamics of Structure: What is the interplay of different types of knowledge?	Knowledge Dynamics and Innovation: How does knowledge dynamics relate to innovation?
Individual Focus on individual actors (teachers)	Dynamics of knowledge production, use, mediation <i>Example:</i> research-practice link through engagement of practitioners in and with research	Dynamics of knowledge structure through teacher education and teaching experience <i>Example:</i> interplay between procedural and declarative knowledge	Innovation as the interplay between knowledge production and use: applying new knowledge in practice, producing knowledge based on practice
Social Focus on social groups, communities, organisations, networks of actors	Dynamics as knowledge construction, flow and brokerage <i>Example:</i> communities of practice, social networks	Dynamics of knowledge structure: interplay between explicit and tacit knowledge <i>Example:</i> organisational knowledge management	Innovation as new knowledge and practices constructed in and/or spread across social groups; innovation in knowledge management
How does knowledge emerge?			
Socio-material Focus on systems of human actors and material elements	Knowledge creation, assemblages of knowledge practices <i>Example:</i> inquiry-based knowledge creation involving interactions with actors and material entities (objects, tools etc.)		Innovation as emerging knowledge practices
Complexity	Individual human actors, social groups and the elements of the material world as a system Knowledge dynamics as the complex interactions of these elements at multiple levels. Innovation, knowledge and learning as emergent phenomena.		

Table 1. Framework for knowledge dynamics and how it relates to innovation
 Note: Topics coloured in grey in this table will be addressed in the second part of the paper.

As all classifications of human activities are embedded in a complex world, this framework is also partial and simplistic, necessarily containing overlaps. Nevertheless, it is useful for highlighting the different analytical angles of a complex phenomenon. This diversity of interrelated analytical angles is, in fact, integrated in a complexity view of teachers' knowledge dynamics, which, as the second part of the paper will suggest, proves useful for reflecting on the connection of innovation and knowledge dynamics.

An individual perspective

In some approaches knowledge has a definite form and is viewed as a property of an individual mind, while learning is primarily a cognitive concept and is understood as growth in knowledge, or knowledge acquisition (Paavola, Lipponen, & Hakkarainen, 2004; Mulcahy, 2012). This line of research often describes two forms of the individual teacher's knowledge: academic and codified (i.e. declarative and explicit) knowledge acquired in higher education, and practical and highly contextualised knowledge (i.e. procedural and mostly tacit) (OECD, 2000; Wilson & Demetriou, 2007). Research on teacher's knowledge from this perspective defines various content dimensions of teachers' knowledge (e.g. Shulman, 1987; Ball, Thames, & Phelps, 2008; Guerriero, 2017) and looks at how individual teachers acquire and use this knowledge. This approach takes account of aspects of both the dynamics of individual teachers' knowledge and that of the knowledge base of the teaching profession.

More broadly, individual approaches look at teachers' professional competence, which is best captured by multi-dimensional models including knowledge of the subject and pedagogy, motivational-affective characteristics, beliefs as well as decision-making skills (Baumert, Kunter, Blum, et al., 2010; Blömeke, Gustafsson, & Shavelson, 2015; Blömeke, 2017). Knowledge is the basis of professional judgements in teachers' daily practice, which enables them to select appropriate teaching approaches (pedagogies) and apply those in the instructional process (Guerriero & Révai, 2017). A number of studies focus on how teachers' practice and knowledge change as a result of initial teacher education and continuing professional development, and how these are related to motivation, self-efficacy and beliefs (e.g. Timperley et al., 2008; Cordingley, 2015).

Dynamics of knowledge production, use and mediation

It has been argued that education is characterised by a lack of evidence-based practice, and educational research is not carried out in a cumulative way (Hargreaves, 1996; Dumont, Istance, & Benavides, 2010; Levin, 2011; Goldacre, 2013, etc.). If research has the potential to increase the quality of teaching thereby enhancing student learning, strengthening the link between research and practice (as well as policy) has long been on the agenda (Hargreaves, 1996; Levin, 2011). Levin (2011, 2013) modelled knowledge mobilisation as the intersecting union of production, use and mediation (regarded in this case as the three functions of knowledge). This model allows for investigating the dynamics of knowledge between research and practice by looking at the processes through which production and use are linked.

In general, the production of research in the classroom is not or rarely supported, and teachers, unlike doctors, have little time, opportunity and backing to engage in research activities (Révai & Guerriero, 2017). At the same time, research on education is perceived by many practitioners as irrelevant for practice (Cordingley, 2008) or too difficult to access. Arguments and suggestions to change the culture of producing educational evidence, including the research agenda and process, are sometimes controversial. Some argue for using more trials (such as randomised control trials) to gather evidence on what works best (OECD, 2004; Goldacre, 2013); others promote building the knowledge base starting from practice, for example, through lesson observations, analysis, recording and storing or more design-based research (Hiebert, Gallimore, & Stigler, 2002). Nevertheless, there seems to be a consensus about the importance of strengthening cooperation among researchers of different fields; strengthening collaboration of teachers and researchers in knowledge production; or supporting teachers in making their existing practices and the underlying knowledge explicit (OECD, 2007; Cordingley, 2008, 2011).

Innovation in terms of functional dynamics can be captured both as the impact of knowledge production on knowledge use and vice versa. On the one hand, new knowledge applied in practice can result in new ways of

teaching. On the other hand, educational researchers investigating new forms of teaching practices can produce evidence on how they work, what their impact is, and so on, which then leads to growth in the available knowledge base. In both cases, effective mediation mechanisms are crucial. These involve formal and non-formal education, but also, as emphasised above, direct interaction amongst the stakeholders, and mutual engagement of actors in processes of both knowledge production and use. The better the dynamics between these functions are, the more potential there is for innovation.

Empirical evidence from the OECD's ITEL project illustrates one of the above processes, namely whether the knowledge base of the profession is keeping up with recent evidence on teaching and learning (see Box 1. for a summary of the project). It aims to reveal the extent to which new knowledge emerging from research – for example, from the broad interdisciplinary field of learning sciences, including findings from neurosciences and on 21st century competences – is integrated into the collective knowledge base of the profession (Sonmark et al., 2017). In other words, to what extent the dynamics of individual teachers' knowledge correspond to the dynamics of available relevant knowledge.

Box 1. The ITEL Teacher Knowledge Survey

The ITEL project explores the characteristics of teaching as a knowledge profession in the 21st century. After extensive theoretical and conceptual work (Guerriero, 2017), the project designed a survey to address three major policy challenges with data from OECD countries:

- *How can we improve pedagogy for more effective learning?*
- *How can we improve teacher education for more effective teaching?*
- *How can we improve the selection, retention and professional development of teachers?*

The ITEL Teacher Knowledge Survey aims to contribute to answering these challenges by better understanding the nature of teachers' pedagogical knowledge, and more generally, professional competence. It also explores learning opportunities in teacher education, including teaching practicum and professional development, and how teachers' knowledge relates to affective and motivational factors. The study is thus guided by the following research questions:

1. *To what extent do teachers have the knowledge and skills for teaching 21st century skills?*
2. *To what extent do initial teacher education programmes provide teacher candidates with opportunities to learn the knowledge and skills needed to effectively teach students for the 21st century labour market?*
3. *How do teachers' motivational and affective characteristics drive their professional competence?*

The purpose of the pilot phase of the study was to develop and validate an instrument, as well as to explore its analytical potential to respond to the above questions and their relevance for the broader policy challenges. Data collection was based on a convenience sample of three sets of respondents: teachers, teacher candidates and teacher educators in five countries. The final sample sizes are 943, 644 and 361 respectively. One of the innovative features of the pilot is the construction of knowledge profiles that capture the relative strengths and weaknesses of teachers' pedagogical knowledge base as it relates to three core dimensions: instructional processes, learning processes and assessment. The study also looked at the scope and quality of opportunities to learn, teachers' work-related motivation, self-efficacy and professional self-regulation, as well as the interaction of these with pedagogical knowledge. It successfully validated the viability of the approach and formulated recommendations for future work (Sonmark et al., 2017).

For more information about the project, and its products and findings visit: <http://www.oecd.org/edu/ceri/innovative-teaching-for-effective-learning.htm>.

The ITEL Teacher Knowledge Survey addresses one aspect of this question by investigating the extent to which teacher candidates, teachers and teacher educators engage in and with research. Engagement *with* research refers to the different ways in which respondents use existing research evidence, whereas engagement *in* research looks at the extent to which they participate actively in research (see Table 2. for the scales). The pilot study's findings suggest that teacher candidates, teachers and teacher educators engage more with research rather than actively in the process, although the difference is much less marked for teacher educators (See Figure 1.; Sonmark et al., 2017). The report emphasises the role of teacher educators in mediating research evidence, for

which their own engagement with and in research is a necessary condition. As a considerably larger share of teacher educators than teacher candidates engage both with and in research, the report further argues that mediation may primarily take place through a more passive form of knowledge transfer, i.e. having students read, analyse and interpret existing research, rather than actively engaging them.

Engagement with Research	Reading research papers in the domain of learning sciences Reading research papers in the domain of educational sciences Evaluating research findings in terms of validity and reliability Analysing and interpreting research findings in terms of implementation in practice
Engagement in Research	Conducting a research or literature review Collecting and analysing qualitative data Collecting and analysing quantitative data Conducting action research in a classroom or school context Implementing the findings of your action research to change your practice

Table 2. Scales of engagement in and with research in the OECD ITEL study

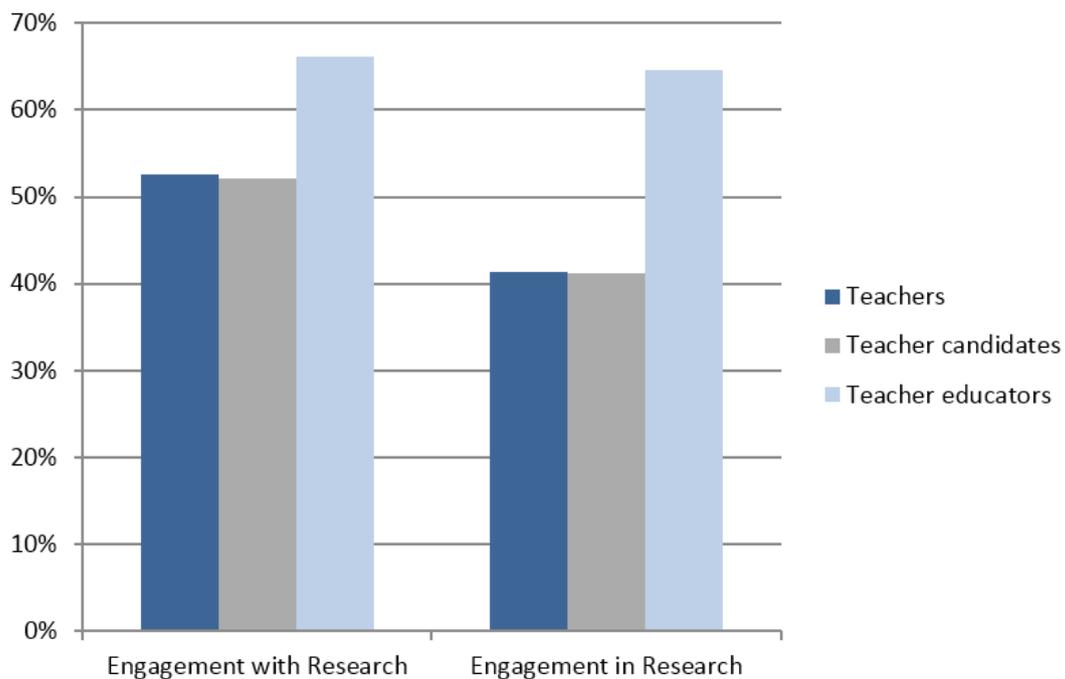


Figure 1. Average percentage of respondents reporting being engaged with/in the research activities defined in the scale. Source: Adapted from Sonmark et al. (2017, p. 80).

The relatively lower share of teachers engaging actively in research may also be due to the specific interpretation of respondents of the term 'research'. While the survey did not explicitly define the term, the first two items in the scale (referring to learning and educational sciences) might suggest that the focus is mostly on academic research. This could have then influenced responses on other items. For example, while many teachers observe their students' actions, interactions and behaviour, measure their development, and design the teaching and learning process on the basis of these, they might not recognise such activity as collecting qualitative and quantitative data.

Evidence suggesting that the dynamics between the different functions of knowledge could be stronger usually thinks of knowledge production in terms of classical academic research in educational and learning sciences (Hargreaves, 1996; Dumont, Istance, & Benavides, 2010; Levin, 2011; Goldacre, 2013, etc.). A broader interpretation that includes practitioner research, e.g. action or design-based research, might be more appropriate when studying innovation. Innovative teaching and learning environments are often characterised by strong dynamics between knowledge production and use in this broad sense. To investigate teachers' engagement with and in research more broadly, qualitative methods, such as observations and interviews are helpful.

Dynamics of knowledge structure through teacher education and teaching experience

Change in individual teachers' knowledge is investigated in some studies as an outcome of teacher education, i.e. through measuring the impact of initial teacher training or professional development on knowledge or practice (Guerrero, 2017; Ingvarson, Meiers, & Beavis, 2005). Research on teacher quality and expertise sometimes uses proxies (e.g. years of experience, qualifications and participation in professional development) to account for change in teachers' knowledge, while fewer studies measure knowledge directly (König, 2015; Guerrero, 2017). The most well-known empirical study is the Teacher Education and Development Study in Mathematics (TEDS-M), which gave rise to a number of national and international follow-up investigations (see König, 2015 for a review), and more recently, the OECD also started to contribute to this evidence base through the ITTEL project. Emerging findings suggest that change in knowledge is linked to characteristics, such as motivation and self-efficacy (Laurmann & König, 2016; König & Rothland, 2012). The actual mechanisms of the change process, the types of knowledge that are developed through teacher education, remain to be explored.

Cognitive psychology traditionally distinguishes between declarative knowledge ("knowing that") and procedural knowledge ("knowing how") (Guerrero, 2017). Teacher education aims to develop both forms of knowledge, and increasingly more emphasis is put on creating links between them. For example, a teacher candidate learns about the concepts and purposes of formative and summative assessment, as well as when to use and how to design such forms of evaluation. Teaching practicum and induction provide opportunities for them to deepen procedural knowledge and reflect on how declarative knowledge is applied in practice. The question is what kind of learning opportunities are efficient in facilitating dynamics between forms of knowledge, and to what extent and how does teachers' knowledge change throughout their career.

The ITTEL Teacher Knowledge Survey is again used to illustrate the way in which empirical evidence can address this question (see Box 1.). This survey distinguishes theoretical-scientific, i.e. formal, systematic and context-independent knowledge, and practice-based knowledge that requires applying professional judgement in context-specific situations (Sonmark et al., 2017). The former would correspond to declarative knowledge, while the latter can be both declarative and procedural. Initial findings of the pilot study suggest that both teacher candidates and teachers have a stronger practice-based knowledge (see Figure 2), although the report also

recognises the difficulty of measuring this type of knowledge through closed-ended questions (Sonmark et al., 2017). Such results indicate that initial teacher education not only focuses on developing declarative (formal and theoretical) knowledge, but it also plays an important role in creating links between forms of knowledge.

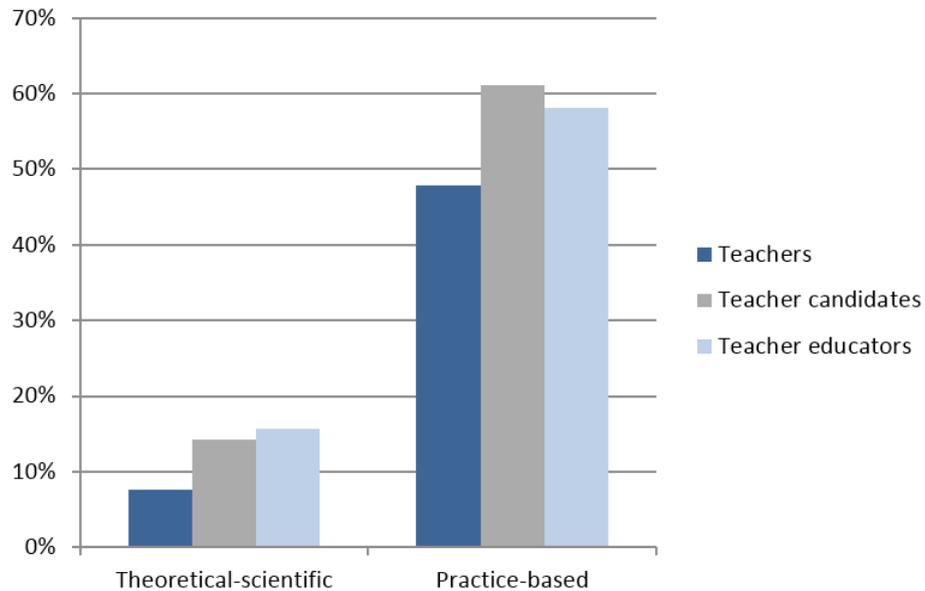


Figure 2. Knowledge profiles based on type of knowledge (percentage of respondents scoring more than 60% of the items in the given dimension)

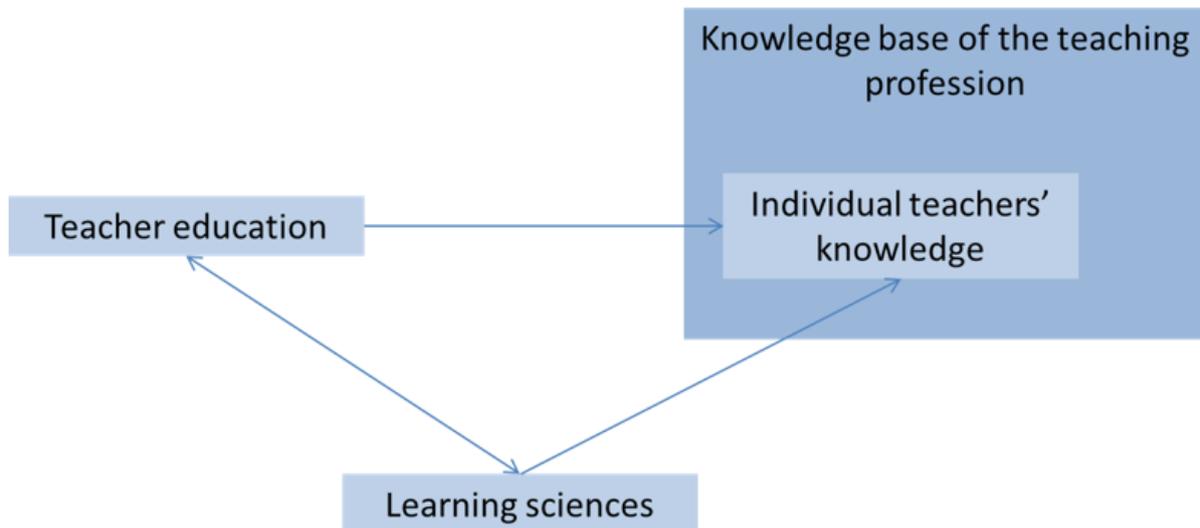


Figure 3. Knowledge dynamics based on an individual focus

Approaches that focus on the individual teacher often consider learning as an outcome of formal and non-formal education, such as initial teacher preparation and structured and organised professional development (Guerrero, 2017). The knowledge dynamics scheme can be simplistically represented as linear relationships between three components: sciences (well-established and emerging theories relevant for teaching and learning), teacher education, through which theories get incorporated in individual teachers' knowledge. The knowledge base of the profession would be the sum of individual teachers' knowledge in this conceptualisation (See Figure

3.). Nevertheless, relationships between formal and non-formal learning opportunities and pedagogical knowledge are not always reported (e.g. there is no analysis in TEDS-M), and when they are, correlations are inconsistent and mostly low (König et al., 2017a, 2017b; Sonmark et al., 2017). Teachers' knowledge is thus also shaped by other processes that provide teachers with informal learning opportunities.

While these mechanisms are indeed important in terms of knowledge dynamics, they fail to capture some crucial elements. Firstly, teacher learning also takes place in informal settings, through work experience, collaboration with colleagues and other actors, or through accessing and engaging with resources individually (hence the direct link from learning sciences to teachers' knowledge in Figure 3) and collectively. Secondly, practitioners' interactions and practice itself are also important sources of teachers' knowledge, and thus knowledge dynamics have to take account of the emergence of new knowledge from these social interactions (Putnam & Borko, 2000; Mason, 2009). In particular, teachers' involvement in innovation processes, such as collaborative curriculum design, impacts their individual and collective knowledge (Voogt et al., 2011). Social theories of knowledge are helpful to account for some of the more complex, non-linear mechanisms, and are relevant for the Innova project as well (Fazekas, Halász, & Horváth, 2017). These are reviewed next.

A social perspective

Recognising the fundamental role of the social and cultural context in the development of cognition has made a huge impact on thinking about learning since Vygotsky's seminal work (Putnam & Borko, 2000; Vygotsky, 1978). An important body of research originating from social constructivism views knowledge as being distributed over groups of individuals and their environment, and emphasises the situated nature of learning. Learning in this sense is based on participation in social groups and the dynamics of knowledge are primarily seen as sharing and co-constructing knowledge in these groups (Putnam & Borko, 2000; Paavola, Lipponen, & Hakkarainen, 2004; Mulcahy, 2012). The way teachers share and construct knowledge in their social-professional environment has been captured in numerous studies and through varying methodologies. Research in this domain includes the investigation of teacher collaboration, communities of practice, teachers' activity and professional learning, and learning organisations, to mention a few examples (see e.g. Gherardi, 2008 for the development of an important branch of such research, coined "practice-based studies").

The common ground of these studies is that they focus on activities ("knowing") rather than on outcomes or products ("knowledge"). Learning and knowledge being situated in a social context, the object of analysis in this view is discourse, interaction, activity and participation, rather than acquisition, integration or accumulation (Paavola, Lipponen, & Hakkarainen, 2004). In terms of knowledge dynamics, the fundamental questions are: how situated "knowing" can be transferred and how it is transformed through interactions; and what characterises those collaborations, communities, and networks that successfully share/transfer knowledge. The nature and structure of social interactions are the principal focus when exploring knowledge dynamics in this perspective.

Dynamics as knowledge construction, flow and brokerage

The social perspective looks at how knowledge is exchanged and shared within and across social groups (knowledge flow and brokerage) and how it is constructed by these groups. This section highlights two research strands – communities of practice and network studies – both of which emphasise the dynamic perspective particularly strongly. Work on communities of practice (Brown & Duguid, 1991; Lave & Wenger, 1991; Wenger, 1998)

is among the first to focus on socially constructed knowledge, both as theories of situated learning, and as part of knowledge management studies. Davenport and Hall understand community of practice as “the level of the social world at which a particular practice is common and coordinated, at which generic understandings are created and shared, and negotiation is conducted” (2002, p. 172).

Drawing on numerous case studies, research in this area includes analyses of different knowledge dynamics processes: socialisation of a new member in the knowledge of a community through participating in practice (Lave & Wenger, 1991), the creation of new knowledge through narrative and improvisation (Brown & Duguid, 1991), and the diffusion of knowledge, for example through brokerage, i.e. interactions that cross the boundaries between communities (Cox, 2005). The concept has also served as a model for knowledge management to enhance organisational performance (Davenport & Hall, 2002; Wenger, McDermott, & Snyder, 2002; Cox, 2005). More recently, communities of practice have been extended to study online communities. Studying teachers' online community of practice in Taiwan, Tseng and Kuo (2014) showed that closer connections among members lead to greater commitment to helping others, which in turn facilitates knowledge sharing in the community. In addition, the authors showed that teachers' membership in the online community fosters a pro-social attitude that increases their willingness to share resources and help other teachers.

An increasingly important research strand analyses interactions as embedded in networks. The concept of network captures the idea that certain elements, for example persons, teams or organisations, are linked through relationships such as friendship, co-working or advice-giving (Borgatti & Foster, 2003; Wassermann & Faust, 1994). Social network theory investigates patterns in the social structure and seeks to describe mechanisms, such as knowledge exchange, responsible for social capital outcomes (Moolenaar, 2012). Three basic assumptions underlie social network research:

- resources, such as information and knowledge, are exchanged through the social relationships among individuals;
- individuals are embedded in social structure and are, therefore, interdependent;
- social networks provide opportunities for individuals and organisations, but can also constrain their actions (only those who access the resources benefit from them) (Moolenaar, 2012).

In this view, knowledge is not necessarily transferred in a predictable and direct manner through formal and non-formal education (as seen in the section on individual approaches), rather the structure and quality of ties among people strongly influence knowledge dynamics (Daly, 2010; Moolenaar, 2012).

As a methodological tool, social network analysis (SNA) has indicated the significance of social networks for organisational performance and innovation, in particular it has revealed insights on knowledge dynamics in educational contexts (Moolenaar, 2012; Daly, 2010). A growing number of studies explore educational change using SNA (Daly, 2010). Some of these investigate the evolution of networks (i.e. why networks and their nodes have a particular structure), while others aim to explain certain outcomes as functions of network properties, and are, as such, interested in the consequences of networks (Borgatti & Ofem, 2010). In terms of educational change, both strands are relevant. When looking at the implementation mechanisms of reform initiatives in schools, the former can reveal how specific interventions affect the structure and nature of teachers' collaboration. Are there new ties, new subgroups that form as a result of these? How do the content and quality of teachers' interactions change? The latter, on the other hand, can reveal how existing network structure and characteristics influence the success of an intervention in terms of the distribution of knowledge and expertise, or change in teachers' practice.

Studying the implementation of educational reform initiatives has helped establish a better understanding of some factors and processes of knowledge dynamics (e.g. Daly, 2010; Coburn, Mata, & Choi et al., 2013; Brown et al., 2016; Hubers et al., 2017;). Research conducted in the United States, the United Kingdom and the Netherlands has for example revealed the following:

- *Density, trust and innovation:* A denser network (i.e. a higher proportion of existing ties [direct connections] to all possible ties in a network) is associated with higher levels of trust among teachers, an open orientation toward new practices and change, and shared perceptions of the school's ability to achieve collective goals (Moolenaar & Slegers, 2010). Frequent teacher interactions also increase the likelihood that teachers will embrace innovations (Moolenaar et al., 2010).
- *Knowledge of the location of expertise:* Typically teachers would first seek advice from those whose values they share (homophily) or who are physically close to them (proximity) and this does not necessarily match the expertise they need. It was observed that when new structures for collaboration are introduced (e.g. dedicated hours with determined focus of the collaboration) teachers seek advice based increasingly more on expertise as opposed to homophily and proximity (Coburn, Mata, & Choi, 2013). Enhancing teachers' knowledge of who has what type of expertise/knowledge can help schools effectively capitalise on the expertise of teachers (Penuel, Frank, & Krause, 2010; Baker-Doyle & Yoon, 2011; Coburn, Mata, & Choi, 2013).
- *Subgroups, brokerage and innovation:* Various subgroups (cohesive groups within a network) exist in a school, typically consisting of teachers teaching the same subject or the same grade. Collaboration within these groups can efficiently strengthen some aspects of teaching and learning, such as reinforcing constructive school norms of formal support, mutual help and shared responsibility for student achievement. Interactions between teachers belonging to different subgroups, on the other hand, can mean access to novel resources and information diversity. Innovation and change are therefore often rooted in collaboration across groups (Penuel, Frank, & Krause, 2010; Moolenaar, 2012).
- *Collaborative skills for higher levels of brokerage:* Knowledge does not flow automatically; explicit attention is needed to develop collaborative skills. For example, Hubers and colleagues (2017) reported varying but generally low levels of knowledge sharing within teacher teams that were specifically set up to work together on collecting and using data to tackle an educational challenge. They also noted a low level of knowledge brokerage (the diffusion of knowledge from one team/subgroup to another through an intermediary "broker" who may or may not be part of one of the teams/groups) that, in addition, decreased over time. Such results draw attention to the importance of specific skills for knowledge sharing as well as structures for effective brokerage.
- *Leadership and innovation:* There can be large variations in the prominence of formal leaders in networks across schools (Moolenaar, 2012). Some findings seem to suggest that formal leaders being the key advice givers and those who connect staff is not necessarily conducive to school improvement and instructional innovation (Spillane, Healey, & Kim, 2010). It has also been suggested that more distributed leadership results in more engagement of teachers in implementing school reforms in certain conditions, such as when there is less access to professional development (Penuel, Frank, & Krause, 2010).

Social network theory has also been applied to investigate the diffusion of social innovation (Borgatti & Foster, 2003). As opposed to social capital research that aims to explain variation in outcomes (e.g. performance and reform implementation) as a function of social ties, diffusion studies seek to explain homogeneity, i.e. how social ties between actors influencing and informing each other lead to shared attitudes, culture and practice

(Borgatti & Foster, 2003). Network diffusion studies look at how an idea, practice or local innovation spreads via knowledge sharing in social networks and can provoke large-scale change through contagion (Centola & Macy, 2007). Contagion of an idea is described through the probability of its adoption by an actor (determined by the proportion of nodes surrounding this actor that have already adopted) and the time of adoption (determined by the lengths of paths connecting the actor to other adoptees) (Borgatti & Foster, 2003; Centola & Macy, 2007).

Findings related to the role of weak and strong ties in fostering innovation are controversial (Davenport & Hall, 2002). Nevertheless, weak ties seem to matter for simple contagions, such as the spread of information or diseases, while strong ties are needed to facilitate complex contagions, such as behaviours, knowledge and innovation (Granovetter, 1973; Centola & Macy, 2007). Position in the network and other variables, such as social status, social responsibility, also matter for diffusion (Rogers, 1962). Centola and Macy (2007) describe four social mechanisms of complex contagion:

- Strategic complementarity: Innovations are not easily adopted by simple transmission of knowledge and they are often costly, especially for early adopters.
- Credibility: Innovations often lack credibility until adopted by direct relationships. Multiple confirmations of the usefulness/effectiveness of the innovation also matter for credibility, especially when the innovation comes from a weak (socially distant) tie.
- Legitimacy: Stronger ties, such as close friends/colleagues participating in a collective action often increase the acceptance of the legitimacy of innovation. Those who do not adopt the innovation are likely to challenge its legitimacy, and innovators may be seen as deviants until there is a critical mass of early adopters.
- Emotional contagion: Collective human behaviour can be amplified in events, as these foster the communication of expressive and symbolic impulses.

In sum, a number of theoretical approaches and methodological tools have shown their potential to deepen the understanding of knowledge construction, sharing and innovation in social groups and networks. Emerging evidence relating to teacher networks and communities are promising, but a number of questions remain open. For example, how does the social construction of knowledge relate to individual teachers' pedagogical knowledge? What are the characteristics of networks and social interactions within them that are conducive to the construction of both a shared and an individual knowledge base? Future studies would benefit from using mixed methods to reveal more about these issues, and investigations should link the individual and the social aspect to better understand their interplays.

Dynamics of knowledge structure: interplay between explicit and tacit knowledge

Economics, in particular organisational literature, applies the social approach to knowledge when studying organisational and territorial knowledge management and innovation networks (e.g. Cowan, Jonard & Özman, 2004; Crevoisier & Jeannerat, 2009; Manniche, 2012). Understanding the conditions for knowledge to be efficiently transferred and made accessible within an organisation or for the general public requires a study of the characteristics of knowledge. To this end, explicit knowledge, i.e. knowledge that can be expressed in symbolic representations (words, text, images) in a way that it is intelligible by another person (Bennet & Bennet, 2008) is often distinguished from tacit knowledge, that is, knowledge that is either not articulable (impossible to describe it in propositional terms) or that is implicit or articulable but with some difficulty (Kimble, 2013). Tacit knowledge is thought to be personal in that it can only be transmitted through direct contact with the person

possessing the knowledge. Efficient knowledge management for example in an organisation would require cost-effective ways of codification, that is, an efficient way of converting knowledge into storable and transmissible messages (Cowan & Foray, 1997).

Evidence on the benefits of codification is, however, controversial. While the use of new technology spreads more easily when knowledge required for its use is mostly codified (e.g. Edmondson et al., 2003; Janicot & Mignon, 2012), many concerns have still been raised about the value of investing in codification. Firstly, different types of knowledge are codifiable to different degrees (Johnson & Lundvall, 2001). For example, procedural knowledge is almost never fully codifiable, but is most of the time partially codifiable. Secondly, the process of codification is never complete, because codification involves the construction of new tacit knowledge (Cowan & Foray, 1997). For example, new codes (e.g. specialised language) need to be understood and interpreted by the person accessing the codified knowledge. Thus, codification does not necessarily reduce the absolute amount of tacit knowledge. Thirdly, researchers also point out that codified knowledge is not automatically transmissible because of the context-dependent nature of some knowledge (Johnson & Lundvall, 2001). For example, teachers in a school develop a new pedagogical approach, describe and document it. When this codified knowledge is accessed by a professional community situated in a different context (e.g. a much larger share of students with disadvantaged backgrounds or a culturally different educational context in another country), that community may not be able to efficiently apply this knowledge. In other words, codified knowledge may not be immediately more accessible to any public.

A well-known model for organisational knowledge creation, derived from numerous case studies, was developed by Nonaka and Takeuchi (1995) and describes the interplay of tacit and explicit knowledge in four levels of entities: the individual, group, organisation and inter-organisational levels. Knowledge creation and transformation are described as a spiral connecting these levels, in which the dynamics arise from the interaction between tacit knowledge and explicit knowledge. They identify four processes of the “knowledge spiral”: socialisation (from tacit to tacit knowledge), externalisation (from tacit to explicit knowledge), combination (from explicit to explicit knowledge) and internalisation (from explicit to tacit knowledge). The spiral corresponds to expanding knowledge over time. Nonaka and Takeuchi’s model includes implications on how knowledge sharing and creation can be encouraged, and through that innovation in the organisation brought about. Since the organisation is seen as a knowledge creator, external training alone will not foster learning and will therefore have very limited impact on innovation. In terms of leadership structures, the authors attribute particular importance to middle managers, who – positioned at the centre of both horizontal and vertical information flows – play a key role in knowledge creation.

Economic simulation is also used to investigate how the dynamics of explicit and tacit knowledge are linked to network structures. Cowan, Jonard and Özman (2004) studied the impact of networks on knowledge growth in industries. Their findings reveal that networks that are spatially clustered (composed of geographically tightly knit groups with a high density of ties) generate higher long-run knowledge growth when there is a high amount of tacit knowledge. As teachers’ knowledge is often thought to be largely tacit (OECD, 2000), this result suggests that an education system may have a higher potential for knowledge growth, and thus innovation, if its school network is clustered.

Knowledge management literature is generally concerned with how organisational (or more broadly, territorial) knowledge can be consciously managed for higher performance. A particular form of innovation is targeting knowledge management mechanisms directly. For example, Dave and Koskela (2009) report a case of collaborative knowledge management as an innovation in the construction industry. This case study describes how a

social web application provided a new way to create knowledge by taking employees' ideas through an iterative cycle of discussion. The tool allowed sharing both tacit and explicit knowledge. Another similar example from the field of education is reported by Baker-Doyle and Yoon (2010), who studied the impact of a platform introduced in a teaching community to make their different expertise more transparent. In this perspective, innovation can partly be captured as new ways of knowledge management.

The interplay between tacit and explicit knowledge at the group and organisational levels, and the various forms of knowledge management are relevant for studying the emergence of innovations in schools, as well as their diffusion within and across organisations.

Summary and pending agenda

This paper set out to investigate how the dynamics of teachers' knowledge can be described and linked to innovation in education through existing evidence from different disciplines. This first part reviewed the individual and the social perspectives as analytical angles. Individual teachers' knowledge changes and transforms as a result of teacher education, as well as through the interplay between knowledge production and use. These processes can give insight into how innovation might emerge and spread as new knowledge becomes integrated into practice, or as it is produced through observing and analysing practice. The social angle considers teachers and professional practice as embedded in a social environment. This perspective captures dynamics through the processes of collective knowledge construction, knowledge sharing and brokerage in professional communities and networks. In terms of structures, the interplay between tacit and explicit knowledge is of particular concern for knowledge management in organisations or wider communities. Innovation can here be considered as new knowledge and practices constructed in and/or spread across social groups, but also as new ways of managing knowledge.

These perspectives fit in the dynamic model of the Innova research presented in this issue (Fazekas, Halász, & Horváth, 2017), which examines the different factors affecting innovation at the individual, group and organisational levels. Knowledge dynamics processes (such as codification, knowledge exchange in teacher networks or using new theories in teaching) at these levels are among the factors that influence innovation. Therefore, understanding the various conditions that are conducive for certain processes and those that are hindering them, also contributes to the understanding of innovation processes. As this paper suggests, mixed-methods approaches that link the individual and the social aspect, such as the Innova research, are particularly useful for investigating knowledge dynamics.

While focusing on individual teachers and on their social embeddedness is relevant to the study of the dynamics of teacher knowledge, these do not account for the complexity of the related mechanisms. Teachers do not only interact with other actors, but also with a wide range of resources such as school books, classroom objects, online toolkits and technology. They engage with them, interpret them and if they find them relevant and applicable to their practice and context, apply them. Such interactions with the material world also affect teachers' knowledge of teaching and learning. Hence, the socio-material perspective, covered in the upcoming second part of the paper, looks at how knowledge dynamics can be described through teachers' interactions with actors and material entities. The question of how these different analytical angles complement each other is also explored in the second part.

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