Forms of Knowledge and Modes of Innovation

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The STI and DUI Modes of Learning and Innovation

- The STI/DUI distinction was first developed in a 2007 Research Policy article that Bengt-Aake Lundvall and I published with other colleagues at Aalborg University. I'll spend some of my time today to consider how the distinction has been operationalized in subsequent research in the field of innovation studies. But I want to preface this by going back to what we refer to in the paper as a tension at different levels - enterprise, regional and national - in research on innovation and innovation systems. We also suggested that there is a strong STI bias in policy analysis and policy frameworks designed to promote innovation.

A preliminary definition

- At its simplest STI refers to innovation based on R&D and the use of *codified scientific and technical knowledge.*
- DUI refers to innovation based on processes of learning through *doing, using and interacting*. You will probably notice the affinity with the idea of innovation depending on interactive learning in Lundvall's work on NIS.

The tension between the STI and DUI modes

- At the level of the enterprise this tension can clearly be seen in the effort to reconcile knowledge management tools based on the use of codified and centralised knowledge, with those designed to mobilize and use tacit knowledge (e.g. communities of practice, organisational routines).
- As we move into a new era of digitization, cyber-physical systems and AI there may be an even greater tendency to think that codified forms of knowledge can be used to good effect to the exclusion of tacit and experience-based knowledge. Think of the literature on the employment effects of robots and AI.

Regional and National levels

- The tension here can be seen in the effort to reconcile approaches to innovation systems focusing on the importance of R&D expenditures, and expenditures on the formal training of engineers and scientists with third level degrees, with those emphasizing the importance of interactive leaning and the exchange of tacit knowledge more apparent in work on NIS
- The DUI emphasis is probably more apparent in work on RIS than on NIS, given the strong Marshallian tradition of focusing of knowledge externalities or non-pecuniary externalities.

Is there an STI bias in innovation research

- There have of course been many and very influential scholars that have given an important place to tacit knowledge and experience based learning in their research on innovation at different levels
- At the level of the firm, Penrose's analysis of the difference between resources and services in the analysis of growth through diversification.
- Nelson and Winter and their analysis of tacit and contextualised knowledge in organisational routines.
- At the level of nations in addition to Lundvall there is C. Freeman work on the basis for incremental innovation in the Japanese innovation system.

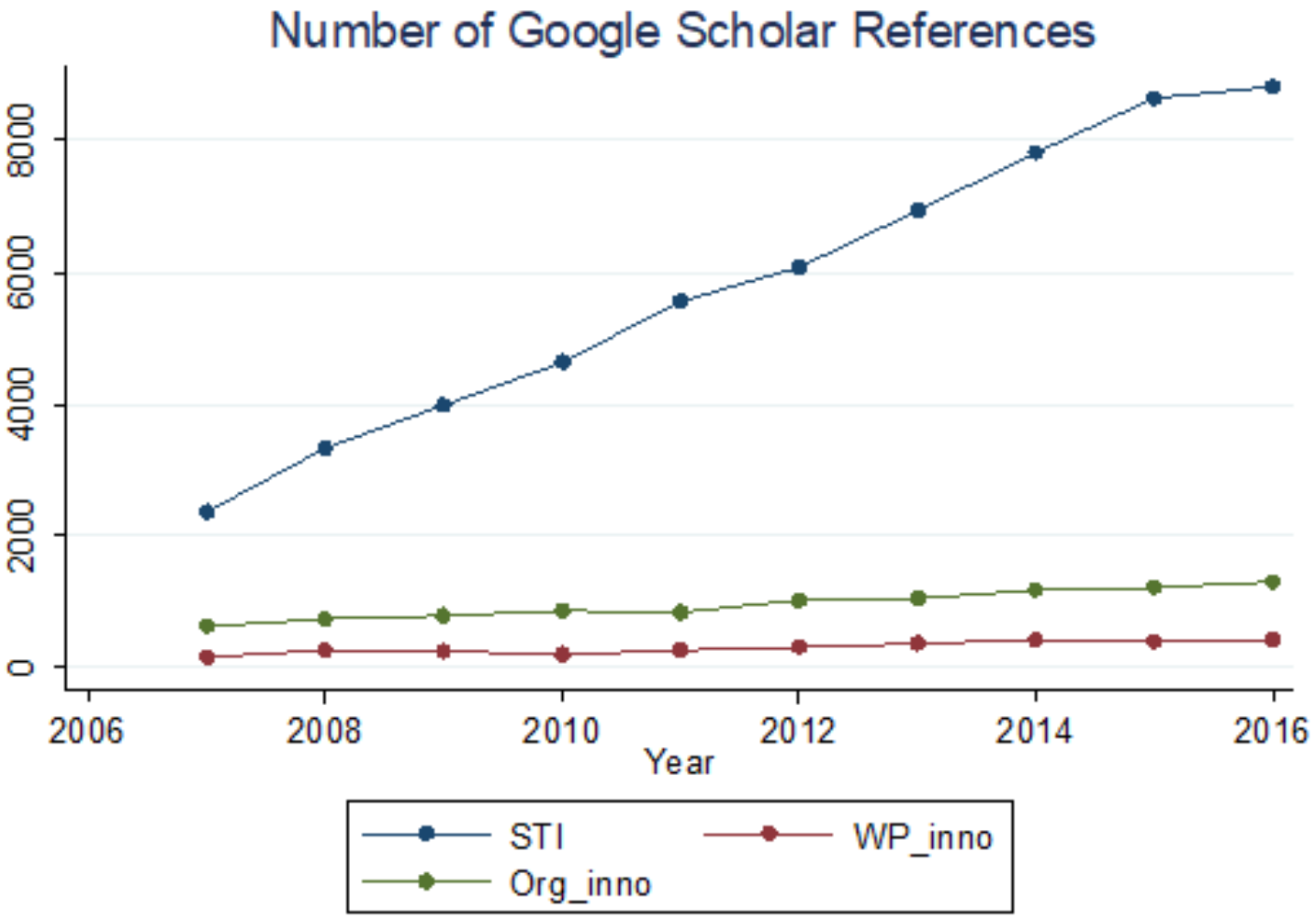
Penrose on the knowledge-based limits to growth through diversification

- "Extensive planning requires cooperation of many individuals who have confidence in each other, and this, in general, requires knowledge of each other. Individuals with experience within a given group cannot be hired from outside the group, and it takes time for them to achieve the requisite experience."
- "It follows, therefore, that if a firm deliberately or inadvertently expands its organisation more rapidly than the individuals in the expanding organisation can obtain the experience with each other and with the firm that is necessary for the effective operation of the group, the efficiency of the firm will suffer, …in extreme cases this may lead to such disorganisation that the firm will be unable to compete…and a period of stagnation may follow."

Chris Freeman on the basis for incremental innovation

- “As empirical evidence and analysis began to accumulate about industrial R&D and about innovation, both in Japan and in the United States and Europe, it became increasingly evident that the success of innovations, their rate of diffusion and the associated productivity gains depended on a wide variety of other influences as well as formal R&D. In particular, *incremental innovations* came from production engineers, from technicians and from the shop floor. They were strongly related to different forms of work organisation.
- Formal R&D was usually decisive in its contribution to *radical innovations* but it was no longer possible to ignore the many other contributions to, and influences upon the process of technical change at the level of firms and industries”

Evidence from Google Scholar



Is there a STI bias in policy frameworks?

- When we wrote the paper in 2007 the evidence appeared irrefutable. The EU's innovation strategy focused heavily on R&D and science to the exclusion of the organisational dimension. Is this still true?
- On the face of it, there would appear to be some progress. Developing indicators of workplace innovation is on the Commission's agenda and there is now a webpage devoted to it and to the activities of the EUWIN (European Workplace Innovation Network). (networkhttps://ec.europa.eu/growth/industry/innovation/policy/workplace_fr)

The DUI dimension in EU Policy Framework

- However, on the Commission's Innovation policy platform page, of the ten listed relevant policy indicators 6 pertain to various categories of R&D and the others to ICT investments, expenditure on tertiary education, employment in S&T occupations and internet users.
- A look at the 2018 version of the Innovation Scoreboard leads to the same conclusion. No real progress.
- One of the constraints here is the lack of suitable indicators of the DUI dimension since policy making, especially at the EU level, relies on harmonised measures for benchmarking and for evaluating progress towards meeting targets and goals.
- I'll come back to the question of survey measurement later.

Elaborating on the distinction between STI and DUI modes

- We defined the STI mode in terms of the use of codified scientific and technical knowledge.
- One point that we make is that scientific and technical knowledge are not the same thing even if both may be codified. As Nelson points out, “much of practice in many fields although codified, consists of design practice involving solutions to problems that professional engineers have learned ‘work’ without any particularly sophisticated understanding of why”. In short “know-why” with out a real scientific foundation.
- This provides one hint at the interconnections between DUI and STI. The origins of much science-like technical knowledge is practice and experience only some of which occurs in the R&D labs of large firms

The interconnections between STI and DUI

- A related point is that scientists working at the frontiers of their fields in the R&D departments of large firms will often be working with knowledge that is only partially codified. They will draw on a combination of their know-why and experience-based know-how in making experiments and interpreting results. Science's contribution may be more indirect by providing powerful tools like computer simulation for testing and experimenting new departures.

DUI's role in embedding codified technical knowledge

- One of the most important point we wanted to make about the interconnections between the modes is that enterprises rely on process of interactive learning and experience in embedding technical knowledge and capabilities in an organisational design capable of coordinating complex processes for producing and commercializing new products or technologies. What's called firm *competence* of *capability*
- The point is that an innovation is not defined simply in terms of a new piece of technical or design knowledge but in terms of the ability to coordinate the successful production and commercialisation of a new product or technology. And much of this knowledge will be firm-specific and highly contextualised and tacit as many scholars have observed

Is the DUI mode necessarily informal?

- As work on organisational routines has made clear, the routines and practices which assure coordination within groups or even across services can emerge spontaneously as people adapt and search for solutions to the problems they face in daily work.
- However, we observe that organisational practices can be designed in ways that support learning through doing, using and interacting and that organisational structure and forms of work organisation matter. If they didn't there would be little scope for policy to improve organisational performance and much less to talk about and write about.

Incremental vs radical innovation

- Should DUI be equated with incremental innovation and STI with radical innovation? Incremental innovators are likely to rely heavily, though not exclusively, on DUI, and radical innovators will need to draw on formal scientific and technical knowledge at the frontier of their fields
- Still, from what I've said, in general both modes will be present to some degree in all innovating organisations. The point we want to make in the article is that firms adopting a strong version of the STI mode with a strong version of the DUI mode will tend to excel in product innovation.

The choice of indicators

- The work organisational and managerial practice variables we used in our paper were inspired by the literature on high performance work places as well as the research on organisational design (Lam and Mintzberg). For interactive learning we use an indicator of close relations of cooperation with customers. We recognised that it would have been preferable to have to had an indicator of the type of cooperation and the extent to which it I based on formal and codified elements of knowledge exchange. But we didn't have the distinction in our data set. The practice of seeing cooperation with customers as DUI in style and cooperation with universities as STI in style has become the norm in the literature

Choice of indicators

Table 1
Indicators of DUI- and STI-mode learning

Indicators	
DUI-mode learning	
Interdisciplinary workgroups	1 if the firm makes some use of interdisciplinary groups, 0 otherwise
Quality circles	1 if the firm makes some use of quality circles, 0 otherwise
Systems for collecting proposals	1 if the firm makes some use of systems for collective proposals, 0 otherwise
Autonomous groups	1 if the firm makes some use of autonomous groups, 0 otherwise
Integration of functions	1 if the firm makes some use of integration of functions, 0 otherwise
Softened demarcations	1 if demarcations between employee groupings have become more indistinct or invisible during 1998–2000, 0 if they are unchanged or have become more distinct
Cooperation with customers	1 if the firm has developed closer cooperation with customers during 1998-2000 to a high extent, 0 if to a small or medium extent or not at all
STI-mode learning	
Expenditures on R&D as share of total revenue	1 if the firm's expenditures on R&D are positive, 0 otherwise
Cooperation with researchers	1 if the firm cooperates with researchers attached to universities or scientific institutes rarely, occasionally, frequently or always, 0 if it never engages in these forms of cooperation
Indicator for workforce composition	Register data indicating whether a firm employs scientifically trained personal. 1 if the firm employs scientifically trained personal, 0 otherwise[a]

[a] Scientifically trained personal includes personnel with a bachelor, master or Ph.D. degree in the natural sciences as well as civil engineers.

Table 2
Clustering of 692 Danish firms based on latent class analysis: probability that a firm will be characterised by a policy/practice according to cluster

	Low learning cluster	STI cluster	DUI cluster	DUI/STI cluster	All firms
Makes use of interdiscipl workgroups	0.1155	0.0143	0.5448	0.9888	0.3960
Makes use of quality circles	0.0159	0.2670	0.5054	0.5483	0.2890
Makes use of systems for proposals	0.1481	0.3554	0.6253	0.5757	0.3931
Makes use of autonomous groups	0.2145	0.4427	0.5320	0.6139	0.4090
Makes use of integration of functions	0.1346	0.2254	0.5545	0.6392	0.3642
Demarcations more indistinct/invisible	0.2709	0.4879	0.5671	0.6256	0.4494
Cooperation with customers high	0.2582	0.4292	0.5512	0.4970	0.4090
R&D expenditures positive	0.1002	0.9875	0.2977	0.8742	0.4017
Cooperation with researchers positive	0.1088	0.8586	0.2195	0.9550	0.3829
Employs scientifically trained personal	0.0854	0.3544	0.1091	0.6826	0.2341
Unconditional probabilities for each cluster	0.4050	0.1099	0.2974	0.1877	1.0000

Table 4
Logistic regression of learning clusters on product/service innovation

	Model 1 (without controls)		Model 2 (with controls)	
	Odds ratio estimate	Coefficient estimate	Odds ratio estimate	Coefficient estimate
STI cluster	3.529	1.2611**	2.355	0.8564**
DUI cluster	2.487	0.9109**	2.218	0.7967**
DUI/STI cluster	7.843	2.0596**	5.064	1.6222**
Business services			1.433	0.3599
Construction			0.491	−0.7120*
Manufacturing (high tech)			1.805	0.5905*
Manufacturing (low tech)			1.250	0.2229
Other services			0.747	−0.2923
100 and more employees			1.757	0.5635*
50–99 employees			0.862	−0.1481
Danish group			0.859	−0.1524
Single firm			0.521	−0.6526*
Customised product			1.378	0.3203
Pseudo R^2	0.1247	0.1247	0.1775	0.1775
N	692	692	692	692

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Our main conclusion

- Our principal conclusion was about the value of mixed strategies combining a strong version of the DUI mode with a strong version of the STI mode. We recognized that mixing the modes may not always be easy and that it is a major task of knowledge management to find ways of integrating them.
- Another major conclusion was about the need for better data at the enterprise level as a basis for constructing DUI indicators including aggregate indicators that could be used in benchmarking exercises. This remains true today even if there has been some progress. I'll come back to this at the end of the presentation

Extensions of the research (1)

- One kind of extension of the research has been to go more deeply into the characteristics of the DUI mode and in particular to investigate its importance for small enterprises. This fits into a larger literature focusing, on the one hand, on non-R&D innovators and, on the other hand, on trying to better understand what is distinctive about innovation in small or even micro firms
- A recent RP paper by Jörg Thomä on the use DUI mode by small firms in Germany, many without formal R&D expenditures, illustrates one kind of extension. There has been work with a similar focus on small enterprises by Davide Parrilli on the Basque region.

Use of factor and cluster analysis to identify mixed modes

Table 1
Factor analysis of the distinctiveness of innovation competencies (principal component factoring, varimax rotated factor loadings, higher loadings are marked in bold).

	Factor 1	Factor 2
Development of new technical solutions	0.266	**0.627**
Scope for development via 'trial-and-error'	0.372	**0.495**
Strong individual responsibility of employees	**0.805**	0.051
Creativity of employees	**0.828**	0.120
Incentive schemes for employees to innovate	**0.739**	0.150
Stimulation of internal competition between projects	**0.490**	0.317
Internal co-operation between departments/firm units	0.363	**0.512**
Inclusion of external partners in projects	−0.039	**0.777**
Interpretation:	Personal knowledge and human resource management	Technical problem-solving through trial-and-error and interaction
Proportion of variance accounted for:	30.78%	20.55%

Note: The factor analysis is based on observations of 3307 companies who provided full information on the eight competency variables. The sample size of the later cluster analysis only amounts to n = 2695 (see Table 2). The reason is that cluster analysis also requires full information, i.e. not only on the two factor scores, but also on the other two clustering variables.

Source: J. Thomä, Research Policy 2017.

Principal conclusions

- Firstly, that mixed modes tend to perform better in terms of product and process innovation even for this population small firms, many operating in sectors with low R&D intensity.
- Secondly, the author finds that firms with a very weak use of the STI mode and a lack to technical competences tend to focus on organisational and marketing innovations to maintain competitive advantage (ie. Non-technical innovation)
- Draw a similar policy conclusion on the need for public support measures to foster STI mode learning in SMEs in Germany.

Extensions of the research (2)

- Another way in which the research on STI/DUI has been extended is using it to better understanding the features of regional or local innovation systems
- Interestingly a number of the more widely cited publications developing the STI/DUI distinction have focused on Norway and more precisely on Norwegian regions or localities.
- Why Norway? Fitjar and Rodrigues-Pose (2013) quote an article by Jan Fagerberg with respect to what the OECD refers to as the 'Norwegian paradox'. Low R&D intensity with relatively high productivity.

The Norwegian paradox.

- Reflects to some extent the R&D bias in policy assessments. R&D intensity is strongly determined by industrial structure and Norway is relatively specialised in natural resource based industries which compared to high-tech spend less on R&D.
- 2010 Figures on GERD as a % GDP. Sweden 3.2; Finland 3.7; Denmark 2.9; Norway 1.6
- 2017 Global innovation index: Norway ranked 19th, well below Sweden 2nd , Finland, 8th, and Denmark 6th
- Norwegian industries rely more on incremental than radical innovation. Firms in many sectors are strong in the DUI mode

Fitjar and Rodrigues-Pose (2013)

- Fitjar and Rodrigues-Pose, two Norwegian researchers, in an ambitious paper set out not only to asses the importance of the DUI and STI mode for a sample of Norwegian forms but they extend the analysis in two ways: one they distinguish between what they call incremental and radical innovation, and two they explore cooperation within regions and as well as outside with firms outside the region.
- Their main focus is on interactive learning between firms and in common with our paper cooperation with customers is used a s a proxy for DUI while cooperation with universities and research institutes is used as a proxy for STI

Table 3
Number and share of firms collaborating with different types of partners.

Partner type	Number of firms	% of firms	S.E.
Other firms within the conglomerate	830	51.7	1.2
Suppliers	1214	75.7	1.1
Customers	1150	71.7	1.1
Competitors	606	37.8	1.2
Consultancies	774	48.3	1.2
Universities	399	24.9	1.1
Research institutes	346	21.6	1.0

Table 5
Share of firms collaborating with partners within and outside the region.

Partner type	Regional	Non-regional
DUI non-supply-chain	28.4 (1.1)	19.0 (1.0)
DUI supply-chain	67.0 (1.2)	61.5 (1.2)
STI	48.0 (1.2)	29.1 (1.1)
N	1604	1604

The first number in each cell denotes the percentage share, with the standard error listed in parentheses.

Why the big emphasis on DUI in regional/local innovation systems

- Strong tradition is economic geography of exploring the importance Marshallian non-pecuniary externalities or knowledge externalities which are seen as mainly to do with the transfer of tacit knowledge and dependent on face-to-face contacts and interpersonal interaction.
- The underlying point is the geographical proximity associated notably with clustering favours interaction between firms and the exchange of tacit knowledge which in turn can leading to interactive learning and innovation.
- Proximity, then, supports DUI and incremental innovation

Is proximity a necessary and sufficient conditions for learning.

- The answer to the first condition is clearly no since firms and persons can interact at a distance an benefit in terms of learning if there is sufficient cognitive proximity. That is, they share the same language or codes as a basis for knowledge exchange.
- This in turn leads to the view that for proximity to promote interactive learning there must be some degree of cognitive proximity for interpreting and absorbing external knowledge. Of course being part of a local community with common education and socialisation may contribute to establishing the necessary cognitive proximity.
- See Boschma (2005) for a review.

Can there be too much proximity

- This relates to the literature on *related variety* and the idea that and learning and innovation depend on have a variety of knowledge. If we al have exactly the same knowledge, then interaction will not foster learning. rather it will tend to reinforce existing beliefs and possibly lead to ‘lock-in’.
- At the level of individuals an firms this can be related to work on ‘framing’ and how established mental models or what Boulding referred to as ‘image’ can lead to inertia.,
- At the level of regions this related to the idea that a lack of openness to outsiders can transform innovative clusters into ‘blind-spots’ with a low capacity for learning and adaptation.

Main conclusions in Fitjar and Rodrigues-Pose

- One major conclusion in their work is that DUI mode learning is important for incremental innovation but only to the extent that it occurs within the supply chain. It is not beneficial if it is with competitor. The reason for this remain to be investigated.
- The second and perhaps more interesting conclusion I that collaboration with extra regional partner I more conducive to innovation that cooperation with regional partners a especially in the case of DUI mode cooperation. This support the view of possibly too much proximity leading to lock-in

Limitations of the study

- The distinction between incremental and radical is basically unmeasurable with CIS type indicators. In the case of new to the market innovations the market may be local or national.
- They are critical of using cluster analysis but not doing prevents them from exploring mixed strategies as well identifying cases where firms adopt mainly one mode or another.

The Africalics project on learning and innovation in micro and small enterprises

- The project explores how **micro and small firms** (< 50 employees) in **four** African countries **learn** and **acquire the knowledge** & **competences** needed to improve their innovation capabilities.
  - A unique design with surveys carried out both with employers/owners and with their employees covering
  - A focus on how skills are developed both through on-going work experience and formal training and though
  - Types of equipment and technology used
  - Explore the role of linkages with customers, suppliers and external support institutions

E. Kraemer-Mbula, E. Lorenz, L.Takala-Greenish, O. Jegede, T. Garba, M. Mutambala, and T. Esemu,

“Are African micro- and small enterprises misunderstood? Unpacking the relationship between work organisation, capability development and innovation”

International Journal of Technological Learning, Innovation and Development, Vol. 11, 2019.

Countries and Sectors studied

Table 1 Seven selected sectors in four African countries

Nigeria	*South Africa*	*Tanzania*	*Uganda*
Agro-processing	Agro-processing	Agro-processing	Agro-processing
Clothing and textiles	Clothing and textiles	Metalworkers	Metalworkers
ICTs	Recycling	Repair and maintenance services	Furniture making

Table 4 Distribution of employers and employees interviewed according to establishment size (no. of employees)

Size category (number of employees)	*Percentage of all employers*	*Percentage of all employees*
Employee works alone	n.a.	9.3
1 to 4	36.2	47.6
5 to 9	36.0	28.5
10 to 49	27.8	15.6
Number	144	152

A Taxonomy of learning Mechanisms

	Internal learning	External learning
Formal learning	Formal R&D Formal design and prototype development Knowledge codification	Hiring in employees with third-level education and diplomas Links to higher level education institutions Links to consultancies and research institutions Use of internet, books, manuscripts, patents
Informal learning	Learning on the job Leaning by trial and error Informal knowledge exchange amongst employees	Interactions and knowledge exchange with clients and suppliers Interactions and knowledge exchange with competitors and other firms

Table 10 Percentage of employees reporting each work organisation trait

	Average for all employees
Cognitive features of work	
Learning new things	94.6
Problem-solving	75.5
Making use of one's own ideas in work	89.7
Autonomy in work	
Control over work methods	69.2
Control over pace of work	67.6
Knowledge sharing and team work	
Sharing information with co-workers	90.3
Sharing information with clients	84.7
Sharing information with suppliers	79.2
Team or group work	49.7
Job rotation	64.6
Training and skills development	
On-the-job training	60.7
Training paid for or provided by the employer	27.8
Training off the job provided by an external provider	24.3
Number of employees	152

Table 11 Employees' perceptions of innovation: shares of employees engaged in different work practices according to whether or not new products or processes were introduced at their workplace

	New products introduced	*New products not introduced*	*p-value*	*New processes introduced*	*New processes not introduced*	*p-value*
Cognitive features of work						
Learning new things	98.1	83.3	0.000	97.1	88.1	0.015
Problem-solving	72.0	83.3	0.913	75.0	76.0	0.540
Making use of one's own ideas at work	91.5	83.3	0.080	92.3	82.1	0.037
Autonomy in work						
Control over work methods	75.0	51.4	0.005	73.3	57.5	0.034
Control over pace of work	69.2	66.0	0.388	67.0	80.0	0.994
Knowledge sharing and team work						
Sharing information with co-workers	91.5	85.7	0.160	92.2	84.6	0.087
Sharing information with clients	88.6	77.6	0.006	92.2	64.1	0.000
Sharing information with suppliers	78.6	60.0	0.019	77.4	44.8	0.000
Team or group work	91.7	66.7	0.000	90.4	73.8	0.005
Job rotation	72.3	47.3	0.003	70.3	53.7	0.029
Training and skills development						
On-the-job training	64.4	47.2	0.034	64.7	46.3	0.021
Training paid for or provided by the employer	33.3	13.9	0.013	34.0	14.3	0.009
Training off the job provided by an external provider	22.9	19.4	.334	25.7	17.1	0.133
Number of employees	*108*	*36*		*104*	*42*	

Challenges for the future development of the STI/DUI line of research

- More on how the modes may be integrated and used.
- More on policy implications and how to promote a better mix
- Do we have good measures of organisational dimension of the innovation process
  - What are the available data sources at the national, EU and international levels
- What would be the best survey design to adequately capture the organisational dimension?