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# From Micro to Nanosystems: An Exploratory Study of Influences on Innovation Teams

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***Abstract*—**What influences microsystems (MEMS) and nanosystems (NEMS) innovation teams apart from technology complexity? Based on in-depth interviews with innovators, this research explores the key influences on innovation teams in the early phases of MEMS/NEMS. Projects are rare and may last from 5 to 10 years or more from idea to concept. As fundamental technology development in MEMS/NEMS is highly complex and interdisciplinary by involving expertise from different basic and engineering disciplines, R&D is rather a 'testing of ideas' with many uncertainties than a clearly structured process. The purpose of this study is to explore the innovation teams' environment and give specific insights for future management practices. The findings are grouped into three major areas: people, know-how and experience, and market. The results highlight the importance and differences of innovation teams' composition, transdisciplinary knowledge, project evaluation and management compared to the counterparts from new product development teams.

***Keywords*—**Innovation teams, early phases, Microsystems, Nanosystems, technology developments.

## I. Introduction

TODAY'S innovation teams of MEMS/NEMS companies work on next generation concepts for the integration of evermore functions on micro and nano scale and higher performance at lower cost [1], [2]. However, the capital intensive nature of nanotechnology and materials requires technological and managerial innovation [3], [4].

This study is embedded in the frame of activities of a micro and nanotechnology competence center fostering collaboration and technology transfer between academia and industry. It focuses on innovators' experience from MEMS/NEMS companies, discussing major positive and negative influences on innovation teams in the early phases of the innovation process. For the development of such complex product or process concepts, innovation teams with cross-functional members from a variety of functions are used [3], [5], [6]. The technology itself is of highly interdisciplinary character requesting expertise from different basic and engineering sciences at once [7], [8]. Even though MEMS processes' roots can be found in standard CMOS technologies from semiconductors, most products need specialized process technologies [9].

Projects with development of fundamentally new products and technologies are long, costly, and also bear risks to fail [10], [11], [12]. Such projects are growth engines for companies. However, go/kill criteria focusing primarily on quantitative methods like projected future cash returns or qualitative methods like fits to the firms' base technology are not so good for technology developments due to many uncertainties in investments and profits [13]. Therefore, the key challenge for the companies is the definition of necessary requirements and strategic decisions concerning the organization and innovation teams resulting of high technology complexity and an uncertain market environment. Complexity and changing environments request effective teamwork through all involved scientific disciplines and organizational functions, with the right people playing a major role for success [14].

In many studies on innovation teams, success is investigated as a performance related function of individual factors after project termination such as e.g. meeting defined schedules, commercial and customer objectives. However, especially for long lasting and complex projects, it can be of importance to investigate more on factors from the initial to the maturing project phases. This means moving away from an 'input-output-performance' view on groups [15] focusing more on phenomena and influencing environmental factors on teams [16]. For example, the optimal team composition to start with, team motivation over long time periods, or management support of complex innovations. Usually the innovator himself accompanies or leads the innovation team from the original idea to the final concept and experiences the complete project period. With him knowing the context on the one hand, tendencies could be detected and on the other hand turning points towards project success or failure, caused either by positive or negative influences on innovation teams, could be identified.

## II. Background

### A. Aim of this article

This paper attempts to highlight managerial aspects on innovation teams in the early development phases of MEMS/NEMS. According to Cooper [17] the early phases span the timeframe between the idea stage and development and refer to 'pre-development' [18] or 'fuzzy frontend' [19] activities. The study contributes to the sparse literature in the field of technology development projects of MEMS/NEMS. While most studies investigate R&D or innovation teams over all branches, this research attempts to develop a more

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practical and applied understanding of a specific branch. In particular, does it focus on innovators' experience on interdisciplinary and cross-functional teams.

Numerous studies focus on the identification of direct measurable single factors, e.g. setting of targets and milestones, market assessment and definition, salary increases and bonuses, etc. [20], [21]. Whereas, the objective of this study is a more exploratory understanding of influences on MEMS/NEMS innovation teams. However, there is a lack of studies which describe the more non-measurable factors like personal linkage between leadership, know-how and experience, innovation drivers' characteristics, and market orientation in a long-term perspective. This is the driving force of this investigation and qualitative research approach. By a better understanding of these mostly invisible factors, innovation managers are better prepared to foster the organizational processes and environment for future MEMS/NEMS innovations.

### *B. Literature background*

#### *1) Leadership in innovation teams*

Even though the leadership's core task is a clear strategy definition and communication [22], leadership has to shape and guide the innovation teams tasks. Barczak and Wilemon [23] point out that the team leaders tasks are communication, climate-setting, planning, and interfacing. Roberts [24] found that leadership behaviors plays a critical role in idea generating, entrepreneuring or championing. In that case, major purposes are the achievement of resources, selling ideas, project leading, gatekeeping through information dissemination and personnel coordination, including sponsoring or coaching.

Technology in the early phases is often complex and fuzzy. Several studies found that transformational leadership with inspirational vision and stimulation is of positive influence [25], [26]. Gemmill and Wilemon [27] found by looking at individual team members that leadership has to carefully diagnose the personal attitude of members and their fears towards the innovation project. Norrgren [28] observed that the leadership style is important for the employee's climate perception and learning possibilities in cross-functional teams.

It is widely agreed that strategic leadership of innovations, where top management has given commitment from idea to the product launch, will have a high level of success [29], [30]. Harris and Lambert [26] studied the senior management's role in teams and found that the company's key practices and characteristics like clarifying responsibilities, team-to-team coordination, conflict resolution, organization of information flow, and access to resources are of importance for the positive results.

With respect to high uncertainty of technology projects [13], this research attempts to illustrate what leadership measures and characteristics are necessary for complex and long-lasting innovation projects with a heterogeneous team composition.

#### *2) Innovation driver*

The innovation driver as a project leader or product champion has an obviously important role in innovation teams with a huge variety of required personal and professional skills. Literature proposes several types of human drivers of innovation teams: team leader [31], project leader [32], [33], product champion [34], [35], [36]. While team leaders and project leaders have more or direct access to the innovation team, resources and budget, champions are decisive contributors or enthusiastic promoters of innovations. Ernst [33] points out that it is not always clear whether the product champion is a different person from the project or team leader, and whether the promoting activities come from the officially designated project leader or from other people in the organization.

However, an innovation driver must have the necessary qualifications, sufficient professional expertise, an inordinate interest, and be able to devote her/himself sufficiently to the project [30], [37], [38]. Brown and Eisenhardt [32] observed that drivers have the cognitive ability to combine a variety of factors (e.g. technical and marketing skills, customers preferences) to a holistic view – a vision, and communicate it to others. Vojak [39] focused in his research on visionary leaders and suggests that a visionary leader is more than someone with technical and market know-how. He found that the personality with characteristics like persuasiveness, energy and enthusiasm, confidence, boldness, high self-esteem and self-assurance, but not arrogance, persistence/perseverance, and passionate engagement for their projects supports success. Additionally, McDonough [30] sees drivers as enablers who can act within different hierarchical levels of the organization, and can facilitate the team's efforts.

This research attempts to illustrate more thoroughly the characteristics and the origin, from which technical directions innovation drivers come from, as little research has been done in this direction so far.

#### *3) Team skills composition, structure, and culture*

Many studies indicate that innovation teams with a certain skill mix are likely to be more successful [20], [40], [41]. To solve such complex problems as in MEMS/NEMS, research suggests cross-functional teams to be fundamental [6], [30], [42], [43]. Cross-functional teams consist of different functional areas of the company, providing the opportunity for a timely integration of critical information such as increased access to new knowledge and information, high-quality learning experiences, and facilitated interdepartmental product transfer [40]. Little research has examined teams of technology development projects where the technology's highly interdisciplinary character with considerations over the scientific discipline borders [44] shall be reflected in the team. Especially nanotechnology as cross-sectional technology and basis for NEMS, shows a high degree of different disciplines [45] to be integrated for problem solving. Hence, MEMS/NEMS team structure is critical and has influence on solution competences of the team, but also on the product success in the long run.

MEMS/NEMS teams have to stay partially several years to understand technical interactions [46], [47]. Such timeframes request a certain organizational and team culture. Cormican and O'Sullivan [48] suggest that organizational culture can be described in terms of values, norms and beliefs when members are sharing ideas, take risks, and initiate change. Other research suggest, that the creation of a helpful culture within the team is of advantage, where members freely distribute and share information and practices [41]. Ahmed [49] concludes that the most innovative companies of the future will be those which have created appropriate cultures that nurture and acknowledge innovation at every level. Thus, managerial practices should lead to an open and participative culture where employees have strategic and operational autonomy to attack problems, providing personalized recognition, focus on group cohesiveness, and maintaining continuous slack resources [50].

This investigation seeks to contribute to reduce the deficit of studies of teams in long-term technology projects. Especially, why innovation team members' competences and personalities have to be carefully selected and adapted to the complex MEMS/NEMS characteristics.

#### *4) Know-how and experience – integrating expertise*

The innovation team's combined know-how and experience has to cover a broad field of technological and business expertise. It is therefore crucial for companies to bring as much product, process, and technical expertise as possible into the early phases of the development process [43]. From a technological standpoint, MEMS/NEMS integrate functions on micro or nano scale, which requests technology competences from different scientific disciplines, and collaboration [51], [52]. Thus, MEMS/NEMS are not an engineering direction [53], it is rather a collection of technological capabilities that impact many disciplines from ideas to packaging and manufacturing [54], which should be covered by the innovation team.

The long-term characteristics [47], [53], [55] request also interdepartmental anchorage and expertise from several areas like engineering, production, target market and marketing, and finance [5], [56], [57], [58], [59]. Cummings [60] found that team members actively engaged in external knowledge sharing increases success through unique external sources. For large international corporations Nobel and Birkinshaw [61] suggest strong internal and external oriented networks of relationships for knowledge exchange. However, the knowledge of individuals and ability to navigate the business world as an integrative factor is perceived as more important for success than most of the technical skills [39].

In sum, integrating functions with complex technologies requests expertise from different fields. In this sense, this research seeks to explore the positive and misleading effects of expertise in MEMS/NEMS and how companies deal with the knowledge explosion and opportunities coming from nanotechnology.

#### *5) Market know-how, market entry*

It is widely agreed that the understanding of the customer's needs, his satisfaction, and internal and external communication and customer contact is related to successful new products [18], [62], [63]. However, little research has examined innovation team's role when market is highly uncertain and market entry is far in the future.

For 'really new' product visions, a good sense of the technology and a general sense for the product application of the technology is required [34]. Zirger and Maidique [56] found that the competence of company marketing, its competitiveness and the growth rate of the market has a positive influence on success. Cooper and Kleinschmidt [29] demonstrated that products entering large and growing markets were more likely to be successful. Whereas, Brown and Eisenhardt [32] suggest that well-defined target markets have significant influence on success.

MEMS/NEMS commercialization is critical due to long development cycles as underlying basic science is not available or not yet well understood [64]. Thus, the right time to market is a very critical point as rival technologies will be also commercialized [65]. The market entry is often far in the future, and the entry itself is very often a strategic action [65].

This study seeks to explore reasons why market orientation for MEMS/NEMS is a very anticipating process.

## III. Research Methodology

This research represents the results of a study from successful innovation concepts in MEMS/NEMS technologies. Data were gained from multinational companies in Germany, Austria, and Switzerland. The study uses a qualitative methodology based on semi-structured interviews, which allows interviewees to focus in-depth in significant fields. This research approach further allows the identification of the 'essence' of the interviewees experiences concerning a phenomenon [66], which is in the case of this investigation experience in a specific innovation project over several years. Patton [67] argues that a phenomenon of interest is 'lived experience', which has to be carefully described how people perceive it, feel it, judge it, remember it, make sense of it, and talk about it with others.

### *A. Case study method*

The case study method is especially appropriate for research approaches with exploratory character with a focus on (a) documenting a phenomenon from interviewees' experience within its organizational context, (b) exploring phenomenon outside of well established constructs, and (c) integrate multiple data sources [66], [67], [68].

Innovators were chosen as respondents to cover a maximum of time span of experience due to long development times in MEMS/NEMS over several years [47]. Time spans last from idea generation to an innovation concept for a go or no-go decision by the top management, and if possible until a successful market introduction. The interviewees had a senior level position, with job tenure of more than 10 years in the respective company. They were either the inventor or innovator of a MEMS/NEMS product or process in their company, R&D or project manager with a leader function of the innovation team. Their educational background was mainly from engineering or natural sciences and they held different company functions in their job tenure.

To focus in-depth in significant fields the qualitative methodology was based on semi-structured interviews with structured and unstructured parts. The questions asked to the innovators were based on a previous literature research on interdisciplinary and cross-functional teams, on MEMS/NEMS technologies, and on nanotechnology. Additionally, notes from discussions, the innovators' product and company presentations were taken into consideration, where they pointed out particular project and team issues.

Based on the identified issues a short questionnaire was generated as heuristic framework [16] with the intention of a 'theoretical lens'. The purpose of the short questionnaire was to narrow the field by the interviewee her/himself identifying the most important issues to be studied. Additionally, missing categories were supplemented and finally the types of questions to be asked were shaped.

The structured part of the interview included the following questions:

1. Which kind of leadership has a positive and negative influence on the team in the early phases?
2. What characteristics does the MEMS/NEMS market have and how can uncertainty be reduced?
3. Which team structure(s) promise(s) to be effective for innovations in micro and nanosystems?
4. What are the major characteristics of an innovation driver to lead an innovation team to a successful concept?
5. Which experience and know-how of team members are of importance for the early phases of micro and nanosystems?

### *B. Data collection analysis*

Data were obtained through different sources: (a) presentations and previous discussions with the innovators, complemented with officially available information from scientific articles and company and product presentations, (b) questionnaires based on intense literature research, focusing the interviews on major topics from innovator's perspective, and (c) in-depth retrospective interviews with an average length of 1.5 hours, which were tape-recorded, transcribed and double-checked with interview partners. Additional notes and observations were recorded during presentations, discussions and interviews to receive a further, more distant view. The purpose of the combined data collection method was to structure the complexity of the study, getting a complete picture of the innovation itself, the innovation team, and insights into team dynamics and management processes. According to Eisenhardt [68], a combined data collection method from several sources is in particular useful for new and explanatory studies where a fresh perspective is needed, and which is considerably outside of the well established theories and constructs.

To uncover and examine key issues a qualitative content analysis was used to analyze the results of interviews and data [69], [70]. To do this, an inductive approach was chosen [69], [71] to transform interview transcripts into data that can be compared [72]. The interviewees' responses were coded to quantify and reflect the individual position and experience [73]. In a next step, a coding agenda was used and *post hoc* amended to analyze text and identify common patterns [70]. These procedures and techniques provide a gradual structure for building an explanation about phenomena from the selected cases [74], [75]. The analysis helped to identify phenomena, observations, and ideas presented in the following section.

## IV. Case Analysis

A multiple case study design was used to explore similarities within the sample of 8 innovation projects in MEMS/NEMS. In-depth interviews were conducted with 9 innovators or R&D managers from 7 different multinational companies and one network organization in the field of MEMS/NEMS. The majority of these products or processes are already on the market or a respective market launch is foreseen in a few years. The product selection was accompanied by an intense literature research, product and process and company presentations by the innovators and including internet research with latest news of company or product. The average length of an innovation project from idea to concept with a decision for further development was in the range from 5 to 10 years.

To understand the findings in the context of the cases it is important to understand the technology's characteristics and environment. The following section shall provide basic knowledge for further sections of this study.

### *A. Microystems and nanosystems technology*

Microsystems, or microelectromechanical systems (MEMS), and nanosystems, or nanoelectromechanical systems (NEMS) provide an interface between the computational (virtual) reality and the surrounding environment by transforming physical quantities or perturbations through sensors and actuators [8]. Usually, MEMS/NEMS integrate mechanical and electrical components and functions on micro or nanoscale [1] optimized as an entire system. They provide one or several functions and include in many cases microelectronics [76]. Similar as semiconductors, MEMS/NEMS are manufactured in cleanroom facilities through several batch-fabricated structure-and-etch sequences. However, MEMS/NEMS differ from semiconductor products as they include moving elements on the micro or nanoscale. This can include signal acquisition (sensing), signal processing, actuation, display (mirrors), control, vehicles for performing chemical and biochemical reactions and assays [77]. From technology side, nanotechnology offers a further step towards miniaturization with new structures and functions. Especially mechanical sensors with carbon nanotubes (CNT) are an important driver for miniaturization [1].

### B. Environment of MEMS/NEMS

The field of MEMS/NEMS, is highly interdisciplinary, relying heavily on experimental activities from selection of materials, process validation, design development, and device characterization [7]. Some prominent examples for MEMS are Texas Instrument's DMD™ [47], Bosch's gyroscope for Mercedes-Benz A-class adopted ESP® (*Elektronisches Stabilitätsprogramm*) as standard equipment [78] or Infineon's pressure sensor [79]. Examples of NEMS are IBM's 'Millipede' [80], Samsung's field emission display based on carbon nanotubes (CNTs) [81] or cantilever based sensors in scanning probe microscopies (SPM) [82]. For MEMS/NEMS the business and technical challenges are different from the classic semiconductor problems with longer design cycles, high cost per function, and slower-time-to market [83].

The application fields are diverse and vast. Typical application fields are automotive industry, communication sector, consumer industry, health care, security, and environmental monitoring [7], [84]. Diversity causes difficulties in coherent manufacturing processes, especially packaging is critical, which often endangers commercialization [54]. While MEMS technologies matured the last 20 years there still exist fundamental and technological challenges in NEMS, especially in reproducible techniques allowing mass-production of such complex devices [8]. Moreover, the maturity of MEMS technology resulted also in a market adaption from former technology push towards a market pull [47] as sensors entry more and more consumer applications (e.g. Apple's iPhone, Nintendo's Wii console). Table I provides an overview of the MEMS/NEMS environment.

TABLE I
CHARACTERISTICS OF MEMS/NEMS ENVIRONMENT

| Attribute | Characteristics |
|---|---|
| Technology | Cross-sectional technology and combination of material, engineering and natural sciences. |
| | New functions request know-how and competences from functions to production and measuring/testing level [85]. |
| | Only few standards in manufacturing [54]; no technology road mapping for MEMS/NEMS [86] as for semiconductors, e.g. ITRS [87]. |
| | Long development times > 5 to 15 years or more (e.g. Texas Instrument's DMD™, [47]). |
| Market | Broad application fields and difficult to predict [54], [85]. |
| | MEMS devices are well established; miniaturization and NEMS are considering to bring new functions and/or cost reductions [1]. |
| Organization | Long-term aspects have significant influence on firm's investments and product strategies [13], availability of know-how, experts, and infrastructure. |

### C. Studied companies

Particular firms were chosen due to their long technology tradition and long experience in this field. In addition, their international leading position and successful innovations in MEMS/NEMS, and of course of their willingness to participate in this study, were criteria for selection. The cases were focused on technology innovation projects (products and processes) where management decided to go ahead with further development or with mass production. Further details to the studied organizations can be found in table II.

TABLE II
PROFILES OF STUDIED ORGANIZATIONS

| Name | Contact | Size | Industry sector | Core business of applications |
|---|---|---|---|---|
| Company A | Innovator | Large | Component manufacturer, manufacturing processes | Sensors, automotive, security |
| Company B | Innovator | Medium-sized*) | Component manufacturer | Sensors |
| Company C | R&D manager | Large | Basic research, component manufacturer | IT business, information and communication |
| Company D | R&D manager | Medium-sized*) | Materials and characteristics | Information and communication, imaging |
| Company E | R&D manager | Large | Component manufacturer | Information and communication |
| Company F | R&D manager | Large | System integrator, software | Information and communication, security |
| Company G | Innovator | Large | System integrator | Health care, life science, automation and control, buildings |
| Company H | Innovator | Medium-sized*) | Component manufacturer | Sensors |
| Company I | Manager | Micro*) | MEMS, NEMS industry | Networking association |

*) Categorization according to the recommendation of European Commission (2003/362/EC) [88]

*Note:* Multinational companies which practice research and development in Germany, Austria, or Switzerland, but whose headquarter is not necessarily located in the mentioned country. Their production sites are partly in the mentioned countries, but also in the US and Asia.

## V. Empirical Findings

The use of the case study method allowed to get specific insights into the innovation teams' environment fraught with uncertainty caused through project characteristics and the MEMS/NEMS environment. A breadth of influences related to people, know-how and experience, and market were observed in this study. The purpose of the narrative quotes is to anchor insights in a broader context.

### *A. The role of people in MEMS/NEMS*

#### *1) Leadership roles*

If innovation teams work on future MEMS/NEMS products and processes with a high degree of uncertainty, then what is the leadership's role and how can leadership influence this positively? Three primary critical groups of leadership roles were identified in the projects.

*a) The role of middle and top management*

The senior and top management in the study had an enabling function rather than controlling and monitoring project advances. Technology and concept are in the early phases in a very 'fuzzy' manner that innovation teams had problems to set clear milestones. Innovators commented that "specifying and scrutinizing all statements in the early phases does not always bring positive results". On the contrary, "a good story with substantiated facts" behind a concept was a good key for success. If the management went beyond this point, then results might be in general falsifications and assumptions might become facts, which were actually no facts. Additionally, it was obeserved that in larger MEMS/NEMS firms innovations were rather blocked by the middle management than by the top management itself. On the one hand middle management demanded and promoted innovation, but on the other the willingness to take risk decreased. Often fears of losing responsibilities through new technology approaches were reasons for building up hurdles or just ignoring new concepts. Thus, innovation teams bypassed such situations through management meetings and direct involvement of the top management in the project progress. These results were consistent with findings from other authors in new product development [30], [26].

*b) Innovation driver*

The innovation driver's position and personal characteristics play a key role in interfacing the team and anchoring the innovation project within the organization. They seek for allies and think about networks which could be supportive to the idea, and they energetically produce evidence why an idea is good. Across all cases the position varied from the inventor itself, team leader position up to senior and CEO level. Consequently, drivers are for promoting activities not in a senior position by definition (e.g. team leader or product champion) [33]. Personal characteristics like persistency and sure instinct are needed on the one hand to face expected resistance from different management levels, especially in larger organizations. On the other hand, the innovation driver has to bring impulses to the team to bridge the long period of drought from the idea to a clear concept. Classically, for MEMS/NEMS innovation teams, these people are experts coming from engineering or basic sciences with a willingness to take risks.

The analysis of this investigation suggests that the drivers' role, characteristics and behavior is reflected on three major levels: (a) technical level: she/he initiates, reflects and pushes forward technical ideas and new solution approaches; (b) organizational level: she/he knows the organizational culture for acting, builds up networks and seeks partners for bridging resistances; (c) personal level: she/he shows technology affinity and enthusiasm for the topic, pursues with stubbornness and persistency on the long-term goals. Thus, in this study these observations highlight the importance of a strong individual in the early phases when project advances cannot be managed systematically.

*c) Team leader roles*

The ability of analyzing and transferring the technology problem into required competences and personalities have been the key role for team leadership. Innovation teams work on technology concepts where resulting products and processes are very often years away from realization. Unlike most incremental new product development projects, most of the team leaders had to re-define necessary competences resulting either from non-foreseen project directions or from advances in other technologies (e.g. material sciences, nanotechnology). Team leaders dealt with this deficit by adding internal or external team members with the objective to build up these competencies, becoming independent and gaining competitive advantages.

It was observed that the leadership style was a critical factor in the willingness of team members to take risks that enabled major innovations. A too authoritarian leadership style caused fears and risk taking decreased due to fears of punishment. When leadership style was characterized like a kind of 'fuzzy control' and 'giving someone his head' team members were more willing to work on risky concepts. Additionally, team members felt more encouraged and acknowledged in their creativity when leadership managed to create organizational room for creativity by reducing administrative overhead.

#### *2) Team composition*

The study has shown two critical characteristics of the projects which had to be covered by the team composition. First the technology problem solving of new functions or processes. Second the strategic and long-term aspects of the projects. Both had to be covered by the teams' skills and personal characteristics.

*a) Team members skills*

For technology solving it was identified that interdisciplinary team composition where the problem was separated into respective engineering directions was not sufficient. A team composition was sought where teams' skills had transdisciplinary character [44], [89] where technical solutions were transferred from one to other scientific disciplines. For example a mechanical stabilization problem on microscale can be solved by electrostatics. One innovator explains the thinking from one to other disciplines:

> "As in micro- and nanosystems we do not pursue an engineering direction like mechanical engineering, which is rather uniform. Or the principles of electrical engineering and semiconductor electronics, which are rather limited disciplines. In micro- and nanosystems technology one must be able to do something of everything. For this, chemistry is also very important. … One should also be ready to work oneself into semiconductor technology and signal processing or e.g. how one can fabricate plastic packaging. This means in our case that the interdisciplinarity or the willingness to exceed some specific points which was learned in academia is very important."

The study revealed that teams were less composed by a combination of pure experts, more through different skills for producing new ideas in technology approaches. Across all cases core teams consisted of people from basic and engineering sciences while members of production and marketing were occasionally involved. Therefore, team members could be classified in three major areas: (a) internal experts with breadth and deep experience knowing the company very well, (b) members, recently coming from academia for fresh new ideas, (c) members out of the subjected area transferring ideas from other technological fields.

*b) Team members' personal characteristics*

By selecting different personal characteristics for the team, companies were able to build up new knowledge basis for solution concepts and establish the project within the company. It was observed that especially in the early and creative phases of projects a team mix of generalists as communicators, experts, and 'technology freaks' helped to advance projects. 'Technology freaks' were introduced as lateral thinkers and idea producers. Their resource opened the door for new technology approaches. However, they were not involved in management discussions as one innovator stated:

> "We try to have up to ¼ of our team of such 'freaks' in our team. … They are very important for solution finding and new ways to go. But, sending them into hard discussions, then more porcelain could be smashed than puttied. Thus, for general political issues 'politicians' should be sent."

The personal attitude of team members towards the team and innovation was identified to be critical to the long-term success of the projects. Teams or individuals worked sometimes for years to advance on a single process step. One innovator, for example, stated career-oriented team members or too experienced members can lead the project to wrong directions and failure. Another stated a team might not work when people are too introverted or too egoistic. Thus, the team members' motivation working in the team has to be carefully studied, as it can mislead the project accompanied with disturbances in the team building process. Other writers also noted the personal attitude towards the innovation itself to be of importance for the success of an innovation [23], [90], [91].

*c) Team culture*

A 'culture of errors' was observed to be an integral part of a team culture in MEMS/NEMS. Developing new MEMS/NEMS concepts is rather a testing out of ideas and technology approaches than a traditional milestone oriented development. Additionally, these trial and error approaches requested also an understanding of 'scientific languages' and respective 'opinions' from team members and organization. As one innovator noted "success is also built on failures, because I failed miserably again and again, … the organization should create a culture, where teams have the possibility to commit errors". Teams were located differently, centrally (e.g. corporate technology), locally, regionally and globally. Thus, in this exploration team culture is defined as willingness for collaboration among experts, team creation over geographical distances, and a sprit for democratic decisions.

### B. Experience and know-how

Experience and know-how in this investigation were both enabling and crucial elements. Experience is defined as lessons learned from other projects and functions. Whereas, know-how is a knowledge basis about specific skills and problem solution techniques. Missing experience was the first step towards change as innovation teams had to develop new functions of MEMS/NEMS. In contrast, too much experience leads to preconceived opinions and blocks new innovative ideas and technology approaches. However, less experience can also mean to fall into traps where a lot of others have already been trapped. One innovator stated:

> "Experience for me is two-minded. It is very helpful if somebody made experiences for years or made a lot of mistakes which should not be repeated. But, on the other side this experience (e.g. of 'gurus') is also hindering ideas. The team is corrective. I could tell you several examples, where people not directly related to the subject brought very good ideas. I would evaluate creativity and capability to be innovative in the concept phase as more important than experience."

MEMS/NEMS are cross-sectional technologies and nanotechnology is a precursor for further miniaturization. To realize functions on nanoscale a high degree of different scientific disciplines is requested [45]. This refers to know-how from different engineering and basic sciences (e.g. mechanical engineering, chemistry, and physics). Across all cases a lack of technological know-how from materials science and the integration of functions on chip level were supposed to become a key weakness for companies. The analysis identified that the combination of know-how and transfer of solution approaches from different disciplines plays a key role for new concepts rather than specific skills from a team member.

Not available know-how is either transferred through licensing, joint projects mainly through doctoral students from academia or a direct hiring of the knowledge carriers. Whereas impulses for future topics come from customers, from competitors, internal experts and from publications [92]. However, personal networks were an additional source for know-how and reflection of solution approaches. One innovator noted:

> "Technology is new and progressing fast. Some topics are always missing, and the question is how to manage it. Therefore, inside and outside knowledge sharing networks and collaboration are necessary. You have to trust these people and at the end of the day, you pick up the phone and call them. However, a critical mass of experts should be in the company, as for sure, you cannot rely only on external experts."

These networks are growing in importance with job tenure and position, while graduates still have to build up this network, whereas graduates bring in fresh ideas based on their experience.

Several authors commented on the importance of inter-firm [93], [94] and external networking [95], [96]. In this exploration it was observed that the personal networking on the individual and team level had two origins: (a) intrinsic motivation due to the nature of technology and (b) a factor of motivation and award by the companies through provided web infrastructure and organized expert meetings.

### C. *Market and market entry as a strategic decision*

When MEMS/NEMS market is highly uncertain, then what can be done to receive market information for non-existing products and processes? It was observed that for MEMS/NEMS companies market uncertainty is characterized through high product diversity, miniaturization, and non-existing necessary production equipment for new concepts. However, market studies did not exist for new concepts. One project leader noted on this:

> "Product generations are in general planned. So, if there is a particular new generation of sensor products, there are considerations years in advance, about what the next generation will look like (e.g. with new functions), which is a real anticipating process. Market studies for radical innovations or innovations with a high degree of novelty do not exist."

How can then the team proceed to get such market studies? Based on both, market and continuous direct contact to potential (lead) customers [18] allowed a testing even in the concept phase. An innovator declared:

> "We classify our ideas between the classic technologies and our new approach and see where our product fits. Sometimes, our products are 'too good' and not needed. In the end, you have to take the phone and contact your direct customers, filtering their information and see if it fits and who can need this."

The long time horizon in technology development anticipates also a danger that there is finally no market. Rival technologies or processes and especially advances coming from nanotechnology provided either a new solution approach or increased risk of substitution of complete research activities. Innovation teams tackled this problem by systematically 'plugging through' of any technical solution approach and the involvement of internal experts, customers, competition and observations of recent research results from academia. To get a broader view about future market potentials innovation teams used tool sets like scenario analysis, road mapping on products and processes, and mega-trends analysis [97].

The time of market entry which was in the past influenced by a technology push where new functions were the decisive factor changed now towards market pull [47]. Further, the feasibility of a concept and the readiness for the market depend strongly on packaging and software. Both are prerequisites for the connection of the real and digital world and have to be considered in the concept phase. Consequently, this resulted in a forced adaption of market and product strategy of former mainly technology oriented companies. See the comment of one innovator:

> "Nowadays, we earn our money from that technology push topics, however this changes. The tendency is towards 'market pull' which means that we have to orient ourselves to what the market wants. As the technology comes to maturity, innovations in microsystem technology have to meet market needs as the basic problems are solved."

Market entry of MEMS/NEMS innovations with fundamental new functions is a strategic decision unlike most incremental innovations were market is developed. This was in particular critical of projects with a long innovation phase and high investments. Being too early when market was not clearly developed resulted in market acceptance problems. When being too late there were prices on the market which had reached their economy of scale that a market entrant could not reach. Therefore, market entry is often a strategic decision where initially several years of losses are accepted and profits are returned in the long run.

## VI. Discussion and Conclusion

The present study provides insights on key influences on MEMS/NEMS innovation teams from innovator's perspective. While MEMS technology has already matured applications from NEMS are still quite rare. In this study a breadth of serving or inhibiting influences on innovation teams was observed resulting from people, know-how and experience, and market. The nature of project (technology development) where fundamental new functions require a new process, the technology itself (e.g. MEMS/NEMS, miniaturization trend, nanotechnology) and long-term characteristics with resulting technology and market uncertainty play an additional critical role.

Know-how and experience are a strong element in MEMS/NEMS innovation teams. It was observed that especially in such technology developments know-how and experience are an antagonism of requested expertise and preconceived ideas. Across all firms a certain knowledge basis in developing and manufacturing of MEMS/NEMS was available. However, teams valued more the systematical funneling of new technology approaches and creation of own knowledge basis than focusing on a 'gurus' opinion from former projects. Focusing on one (known) solution approach increased the possibility of dead ends in later project status. Therefore, the build up of one's own knowledge in the long run, especially transdisciplinary capabilities were helpful to develop unique functions, processes, and manufacturing techniques as competitive advantages for new and existing products.

In this investigation it was observed that traditional project management methods with defined milestones as controlling functions or project evaluation methods focusing on financial paybacks were only applicable in a limited way. Project progress was rather shown in an improved concept than in defined development steps. The financial outcome was often compared with traditional new product development projects where the return on invest was calculated on the first generations. These methods rather limited progress or killed projects. Thus, this suggests that projects with fundamental new functions should be evaluated more with qualitative methods where decisions are also based on opportunities, improved capabilities, build up of new skills, and road maps of potential products.

The observation of this study highlights the importance of needs to develop and test new practices that managers are bringing along with MEMS/NEMS innovations. The understanding of the importance and possibilities rising out of these technologies is fundamental for strategic decisions. Unlike their counterparts in new product development, the projects are rare and long-term oriented.

The objective of this study was not to build theories concerning influences about MEMS/NEMS innovation teams. The exploratory approach provides a new perspective how MEMS/NEMS innovation teams are influenced in the early phases. Such developments are long-lasting, complex and interrelated between different fuctional departments and locations locally, regionally, and globally. In large companies these projects are often positioned in corporate technology creating potential products or process serving across several product divisions. A research approach looking inside those innovation teams may provide help in understanding the team environment for future team composition and management.

## VII. Limitations and Future Research

The current study has obviously limitations. First, the research model selected is based on a qualitative approach, whereas perceptional data obviously have limits, and can be biased through a personal and historical context [98]. The qualitative research approach provides a relatively broad perspective where major influences on teams are indicated, but not single ones with most influence on innovation teams' success. Second limitation is the sample size. Even though, sample size is consistent with many studies in new product development and innovation team studies [99], [100], [101], it certainly has its limits for generalization. On the other hand, the results presented are just a beginning, which needs both refinement and further testing in a larger sample and a more statistical data assessment. Such data would also allow investigating on the relative importance of the findings and hypothesis testing in contrast to an exploratory analysis. Third limitation is the company size and regional aspects. This study focused on small and medium and large sized companies in middle Europe, which have already a MEMS history. For smaller companies, and especially start-ups, the organizational settings and communication paths are different and play a minor part in comparison to large organizations.

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