Specifying the pragmatic roots of action research

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Abstract

This paper explicitly shows that the action research methodology is based on the five maxims of pragmatic inquiry: taking a look, cognition, practical utility, fallibilism, and iterative nature. To do so, the paper theoretically reviews the action research methodology itself, but also relates the pragmatic maxims to our own action research efforts to develop technologies to support three different complex engineering projects. In this way, the paper shows that pragmatic inquiry is especially useful in such complex environments. Further, the paper suggests that action researchers who wish to develop technologies in such complex environments can improve their research efforts by specifically accounting for the five pragmatic maxims.

Introduction

Historically, organizational and management researchers have used cognitive research methods to develop technologies that improve complex engineering organizations. These research methods assume that researchers can identify generally applicable problems, represent them, abstract them generally, and finally develop technologies that enable practitioners to stabilize these problems (Simon 1981). Researchers that apply the cognitive methods, assume that final general stabilizations of identified problems are possible and can improve organizational efficiency. While cognitive researchers have been able to develop some technologies that successfully solved problems in organizations, most of the problems these technologies stabilize are characterized by a low scale of complexity. Cognitive research has, so far, failed to support the development of technologies to support more complex organizations, specifically those operating in complex engineering environments.

We attribute the above-described shortcomings of the cognitive method to develop technologies in complex engineering environments to the following two reasons. First, it is often not possible for researchers to grasp existing organizational problems in their entirety. With rising problem complexity, researchers simply lack the ability to understand the problem entirely, adequately represent the problem, generally abstract it, and propose solutions that enable engineering practitioners to stabilize the problem. Second, to stabilize a complex problem, researchers frequently develop overtly complex technologies that practitioners are simply not able to apply in practice. Dependent on the relative complexity of the addressed problem, practitioners lack the cognitive ability to understand the proposed technology, interpret the technology, and enact it within the specific local organizational environment. This dilemma is aggravated by the fast changes in complex engineering environments. Practitioners do simply not have the time to understand, interpret, and enact the proposed technology (Lorino 2008).

To overcome these two barriers, researchers have recently started to use action research methodologies to improve complex organizations (Baskerville & Wood-Harper 96; Susman, 1983; Hartmann et al. 2009). This paper theoretically shows the roots of action research in the pragmatic theory and illustrates these roots using three exemplary cases of our own engineering management research efforts in the areas of construction design decision making with the use of 3D computer models, financial decision making with cost control applications, and the ongoing quality improvement of construction operations with virtual reality technologies. In particular, we show that action researchers belief that any of the possible technologies to improve complex engineering organizations will always be sub-optimal because categories that are a priori chosen for technology development will change as users of these technologies gain new experience about the usefulness and effectiveness of the technology during the technology's use (Lewis 1991). Action researchers, therefore, need to look for what is useful and effective within a group and in this way follow Dewey's (Talisse 2002) pragmatic methods of inquiry that focus on understanding specific problem contexts instead of generalizing problems to as many contexts as possible by taking a direct look at how the members work using ethnographic enquiry methods. Further, the action research methodology also applies the pragmatic maxim of utility that only those concepts or technologies that work in practice are valuable and that researchers iteratively should develop new concepts and technologies, while they accept the possibility that some of them fail – the pragmatic maxim of fallibilism. We hope that by making the pragmatic roots of action research explicit, the paper supports researchers with evaluating whether action research is the right research approach for them and help them with designing and conducting action research endeavors.

The paper is structured as follows: In the next section, the paper briefly introduces the five main maxims of the pragmatic research philosophy. The paper then describes how action research methodology can benefit from explicitly acknowledging these five maxims. Consecutively, the paper uses three examples from the ongoing research work to illustrate how the acknowledgment of these pragmatic roots can support action research and how this enabled us to improve construction engineering practice with new technologies. Finally, the paper concludes with summarizing a number of implications that follow directly from the pragmatic roots of the action research methodology that will help action researchers during their research efforts.

Pragmatic Inquiry

In this section, we will briefly outline the main concepts of pragmatic philosophy. In particular, the section introduces the concepts of *taking a look*, *cognition*, *utility*, *fallibilism*, and *iteration*. The following section then uses these concepts and shows how they form the philosophical basis of action research.

Taking a Look

To improve practice, pragmatic researchers believe that they need to build meaningful new theories upon the existing experimental knowledge of practitioners that they need to explicate first. In doing so, they strive to consider the moral motives of practitioners, their experiences, sensations, emotions, relevance of understanding, desires, political agendas, and their sense of responsibility (Calori 2002). Pragmatic researchers believe that all this knowledge is intrinsically embedded in practice (Cook & Brown 1999; Brown & Duguid 2001) and that, therefore, theory and practice are inseparably inter-related (Rescher 2000, p. 105). Researchers, therefore, need to learn from experience (Rescher 2000, p. 143) and extract practical knowledge by *taking a look* at the day to day practice.

Cognition

During the above described extraction of knowledge from real world practice, pragmatic researchers consider that the experimental knowledge of the practitioners they *look at* is closely related to the practitioners' *cognitive concepts*, such as points of view, language patterns, linguistic frameworks, practice, and cultures (Fine 2007). These *cognitive concepts* vary from practitioner to practitioner, from social system to social system, and from local environment to local environment. Additionally, cognitive concepts vary even for one person according to its present sensory and practical situation (Macbeth 2007). Therefore, the researcher tries, in close collaboration with practitioners, to explicate these concepts to establish a locally systemic (Rescher 2000:92; Carnap 2002) theory. This theory should focus on describing the experiential knowledge of the practitioners within the specific setting that the pragmatic researcher *looks at.* In this way pragmatic researchers hope to avoid developing over-generalized theory that will not work well in the given local context. By acknowledging the existence of varying cognitive concepts, pragmatic researchers realize that theory that is defined in such a way is not absolute and fixed and that it is likely that the theory, but also its underlying system, will change and be replaced during the research effort (Rescher 2000: 33).

Utility

A factual answer whether a chosen theoretical system that is built on the practitioners' cognitive concepts is a good system or not, is only possible by applying it in the practical setting that the researcher works in. This gets to the heart of the pragmatic inquiry: Pragmatic researchers believe that a system is only good if it works in practice (Hacking 2007). They evaluate and legitimate new theory according to its success or its efficacy of application and implementation in practice (Rescher 2000:2) and acknowledge the fact that a notion of truth of goodness always depends on interests derived from cognitive concepts of the practitioners (Macbeth 2007).

Fallibilism

With the notion of utility as to how something works in practice, pragmatic researchers at the same time reject the possibility to achieve authentic knowledge (Rescher 2000:3). Pragmatic researchers accept that they can only come to reasonable beliefs through testing and experimentation in practice and that each of these beliefs may turn out to be false at any time. Pragmatic researchers, however, do not take this pragmatic principle of fallibilism as an invitation to nihilistically question the sense of their research efforts altogether. Moreover, they take fallibilism as an invitation to not strive for perfect knowledge, but for a constant improvement of knowledge. Additionally, by acknowledging the possibility of fallibilism pragmatic researchers make sure that they do not block the road to further inquiry by absolute and premature assertions (Macbeth 2007).

Iterative Nature

With the rejection of trying to find perfect knowledge, pragmatic researchers focus on constantly replacing previous with new and accessing the *utility* of the new by *taking a look* at how well the new works in a practical context. Doing so, pragmatic researchers implement cyclic feedback loops that allow them to constantly improve on practice and, at the same time, evaluate how well the improvements work in practice by trial and error implementations. During the implementation, it is important to, on one hand, insist on principles that proved themselves effectively in application to elevate on previous feedback loops, while at the same time, abandon principles that did not work well to improve in future feedback loops. Overall, pragmatic researchers try to implement the best possible solution at any juncture of the cyclic feedback loops. This iterative implementation allows for an ongoing quality control and, at the same time, for a further devised understanding of the accuracy of previously identified cognitive concepts and the applied research method of the effort. In the end, pragmatic researchers hope that, through the iterative nature of their inquiry efforts, increasingly stable theories will historically emerge and that they are able to continuously improve practice in this way.

Action Research to Develop Engineering Management Technologies

Action research methodology (Baskerville & Wood-Harper 96; Susman, 1983; Hartmann et al. 2009) tries to improve practice by using at least three iteratively repeating steps: Ethnographic participant observation, development of a sub-optimal technology, and implementation of the technology in the context of the engineering project under observation. This section will discuss how ethnographic action research heavily draws on the pragmatic maxims of *taking a look, cognition, utility, fallibilism*, and *iteration* in each of these three stages.

Ethnographic Observation

During the first iterative step of the methodology, the ethnographic observation of practice, ethnographic-action researchers focus on identifying the problem within the specific context on an engineering project. Following Dewey's concept of "truth as communally authorized assertability" (Rescher 2000: 27), the methodology defines context as the environment of an engineering project as it is commonly understood by the engineering practitioners. To get insights into this social understanding, the methodology suggests that researchers use ethnographic participant observation (Jorgenson 1989) during which researchers overtly and actively try to become full-blown members of the respective engineering organization. Hereby, similar to Mead's pragmatist students at the Chicago School of Sociology who already were or tried to become part of the organization they studied (Bulmer 1984), engineering researchers will gain deep insights into the day-to-day realities of the context of the engineering organization under study by becoming engineering practitioners themselves.

Technology Development

After researchers arrived at an in depth understanding about the context of the engineering organization, but also about the problems that the organization's practitioners face, in the second step of action research, they then develop an engineering technology that can overcome some of the problems that the organization faces. It is of importance that the researcher develops the new technology in close collaboration with the organization's practitioners because, according to pragmatism, creative collaboration within organizations is the necessary condition for fruitful, productive, and satisfying social interactions and developments (Mead & Morris 1934). Additionally, contrary to the cognitive approach, this developed technology should merely focus on stabilizing observed problems of the day-to-day realities of the practitioners and not on stabilizing generally abstracted problems. Researchers should be aware that any technological solution will always be sub-optimal even within the context in which they observed the problem.

This sub-optimality is a warning that researchers must deal with during the development of a technology. To develop new technologies, be it logical process improvement technologies or mathematical information technologies, researchers need to a priori fix categories that can represent a problem in its entirety. In consistent problem descriptions hinder the development of technologies. The pragmatism of Carnap (2002) helps to overcome this problem. In line with Carnap (2002), researches should distinguish between external and internal systems. The external system is the real world context of the engineering project with its constantly shifting realities. It is not possible for researchers to derive fixed categories from the external system for technology development. To develop a technology, researchers need to define fixed categories within an internal system that represent an idealized sub-system of the external system. This internal system needs to represent a simplified version of the current state of the external system as it is known by the researcher. In the end, such a priori defined internal systems allow researchers to find answers to the simplified problems that allow them to develop new technologies.

Technology Implementation

The final iterative step of the ethnographic action research methodology entails the direct implementation of the developed technology within the respective context that is the focus of the research effort. This allows for determining the appropriateness of the technology, defined by how well engineers can operate the system (Schilpp 1963). Further, researchers can determine whether the system is an effective solution to stabilize the problems by evaluating how well the system gets accepted by the practitioner community on the engineering project (Rescher 2000:27). If both of these process checks are positive, researchers can assume that the immediate implementation of the pragmatically developed technology already improves organizational work processes and they are in this way presented with evidence for the technology's effectiveness.

Additionally, similar to Garfinkel's (1967) social breaching experiments, the implementation overtly and purposely challenges the realities of practitioners. This, in turn, triggers critical reflections among practitioners about their previous and about their new, with the technology improved, day-to-day work practice. The researchers' roles as full-blown member of the engineering organization, then allow them to engage organizational members into discussions to meaningfully channel these reflections in the next iteration of the three step ethnographic-action research process. Finally, with more and more iterations of the ethnographic-research method in the same organization, as well as across different organizations, general abstractions of the faced problems might arise over time.

Application of the Method to Improve Engineering Organizations

To illustrate how ethnographic action research works in practice, this section describes three different cases of how we used the methodology to improve engineering organizations. We start by describing our action research efforts in improving the multi-disciplinary decision making during facility designs with the use of 3D computer models. We then describe how we applied the method to support the financial decision making during the construction of facilities with cost control applications. Finally, we also describe how we used the method to improve the ongoing quality improvement of asphalt paving road construction operations with virtual reality technologies.

3D Computer Models to support multi-disciplinary design coordination activities

The design of complex facilities, such as hospitals or sport stadiums, is a multi-disciplinary effort. To leverage possibilities to specialize on parts of the design, the overall design work is, therefore, distributed among several companies that are responsible for different sub-systems of the overall design. Each of the participating companies then design a sub-system in isolation, before they mutually integrate each of their sub-designs into an overall design system. During this integration step it is important to identify and resolve as many conflicts between the different sub-designs before the on-site construction starts. Once workers have begun to install physical systems on-site conflicts that designers have not resolved yet will cause construction delays and cost overruns.

In the traditional design process practitioners visualize and communicate their design in two-dimensional (2D) drawings representing the various design systems to coordinate the sub-systems that are designed by different specialists. To improve this process software engineers have developed IT systems that use three dimensional computer models of the facility's sub systems to automatically check for interferences in the different system designs. These IT systems promise to improve the traditional manual and cumbersome design coordination routines (Staub-French & Khanzode, 2008). However, to apply these automated conflict detection systems each of the parties involved in the overall design effort need to present their design in 3D computer models. These models, due to the added third dimension of the presentation, contain a lot more additional information that project stakeholders have to manage. This case describes how ethnographic-action researchers iteratively developed and implemented automated clash detection systems on two hospital projects in California.

On the first project, at the start of the effort, two researchers, one technology manager from the company and one university researcher got closely involved with the project team. They spent a number of days per week on the project, observing the 3D design coordination work of the project team with the new software technology. They also conducted a number of unstructured interviews and intensively discussed issues with current work routines that the researchers identified during their observations. An ethnographic analysis of this data showed that the different design parties struggled with the generation of adequate 3D models for an automated design conflict resolution. Often different team members did not generate 3D models with the necessary level of detail to enable meaningful design coordination efforts using the new software technology.

Together with the practitioners on the project, the two researchers started to develop general guidelines for the content of the 3D design models for this project. The guidelines specified, according to the past experiences of the practitioners on the project, which parts of the design and in what level of detail the 3D model needed to represent these parts. Throughout this effort the researchers worked closely together with the design practitioners of the project. In several, formal and informal interviews the researchers asked the practitioners about their experience regarding commonly occurring conflicts on similar past projects. Hence, they were able to make most of the experiential knowledge of the practitioners explicit. In this way, the practitioners and the ethnographic action researchers developed and implemented a design coordination system on the project. They also published the results of this research effort jointly (Khanzode et al. 2007).

To evaluate the effectiveness of the new design coordination system, the researcher and the practitioners together developed metrics to access the system's utility on the project. They decided together on measuring the overall staff hours and the installation costs of the system and to compare these data with initial estimated budgets based on prior experience. Using these metrics we were able to measure the pragmatic utility on the project, e.g. what was the direct practical influence of the new technology within the practical setting. Overall, both utilities showed a significant improvement of the actual versus the estimated costs and staff hours.

Due to the success of the first project measured by the pragmatic utility, the client company of the project a large U.S. hospital provider wanted to implement this design coordination method on a second project. In line with the iterative philosophy of the ethnographic-action research method and accounting for the possibility that the design coordination technology that worked so well on one project can fail on another project, the client company again approached the implementation with an action-research effort. Similar to the first project a university researcher together with a technology manager of the company that was responsible for the project management of this second project got involved. The two researchers started to ethnographically observe the project team's work with the 3D model based coordination technology carried over from the first project and conducted a number of interviews with the team members. Additionally, the researchers collected all available documents about the construction project, such as schedules, meeting minutes, or construction drawings. An ethnographic analysis of the data showed that it was not possible to simply introduce the previous developed design coordination technology. The analysis of the ethnographic data showed that due to the contractual relations on this project the different parties responsible for the design of this project were not co-located in one office building. This was a significant contextual difference compared to the first project where all design parties worked together locally in one office.

Due to this contextual difference, the implementation of the design coordination method on this project initially failed. All the parties were able to use the guidelines from the first project, though we slightly adjusted them to account for a couple of minor contextual differences, to generate the required 3D models. Further, the software technology was able to meaningfully check the 3D models and identify conflicts between the different sub-designs. However, without the possibility to informally communicate and discuss the conflicts the technology identified, the parties were not able to meaningfully resolve these identified conflicts in a timely manner. The practitioners were not able to understand each others' responsibilities, but also they were not able to make sense of the effects of a solved conflict between two subsystems on all the other subsystems without the possibility to constantly informally communicate with each other.

With this in mind, the ethnographic action researchers started to implement information systems that could support collaborative decision making of all the stakeholders. This system was internet-based and enabled all project participants to formally and jointly manage the resolution of identified conflicts. Again the action researchers developed the system in close collaboration with the practitioners on the project. They focused on understanding the experiential based concepts and the language practitioners used during informal design coordination efforts on this and on previous projects. The researchers used these concepts to design a formal system which enabled the practitioners on this project to coordinate their dub-designs without being collocated in one office area.

Support the financial decision making during the construction of facilities

Many researchers and practitioners have questioned the usefulness of accounting information at the operational level (Joenssen & Groenlund 1988). Managers are often dissatisfied with the financial information they receive because it is not up to date, not reliable, and its categorization does not suit the financial decision making tasks at hand (McKinnon & Bruns 1992). This problem is especially visible with small construction companies that cannot afford to hire trained accountant staff, nor buy, adjust, and implement sophisticated accounting software.

To overcome this problem and to explore the financial decision making processes of small construction companies we conducted ethnographic action research with a small home builder in Northern California. The company we studied offers professional design and construction services for private homes from concept to completion. Overall, five full time employees work with the company: the company's president responsible for customer relations and finances, two construction managers, one designer, and one part-time office staff responsible for financial book keeping.

Following the pragmatic principle of *taking a look,* the first author of this paper got actively involved in the day to day work processes of the company by trying to help with ongoing work wherever possible. In this way, the researcher was able to become a full blown member of the firm's team throughout the four month research effort. This allowed him to get in depth insights into the financial decision making processes that he would not have been able to get with a less active role (Jorgensen 1989:20). The researcher's role on the project was overt. All employees were aware about the intention to do research about financial decision making processes.

This active and overt involvement allowed us to understand the financial process of the company in detail. Overall, the company works with two different kinds of contracts: lump sum contracts and cost-plus contracts. Both contracts usually included a budget from an estimate of one of the two project managers about the overall predicted costs for the house of a client. These budgets contained several line items categorizing different design and construction work tasks. On lump sum contracts this budget was binding for both parties. On cost plus contracts this budget only reflected a preliminary estimate to inform the client roughly about the project costs in advance. Additionally, each of the budget items contained a percentage to account for the company's profit and the company's overhead to maintain general company functions that cannot directly be attributed to a specific project, such as the costs for the company's office space. Lump sum contracts, additionally, contained a final budget that showed the product of the overhead rate with the estimated budget for each of the line items.

To negate accrued costs and to make profit the company generated income by invoicing completed design and construction work to clients. In doing so, the company used two different processes according to the respective project's contract type. On cost plus contracts, the company directly invoiced accrued costs multiplied with the respective overhead and profit percentage of the cost item's respective line item in the contract. The company directly generated revenues by multiplication of the accrued costs with the contractually defined overhead and profit rates for each budgeted line item. On lump sum contracts, one of the two project managers estimated the percentage complete for each of the line items of a project's contract budget every two weeks. The project manager then multiplied these percentages with the budget of the respective line item and directly invoiced the product to the client. On this kind of contract, the company only generated revenues when the costs accrued for a completed line item, not including the overhead, remained under the budget of the item as defined in the contract.

Due to these two different ways to generate profit, we were able to identify two different problems during the financial management of projects. On cost-plus projects, oftentimes, the company's practitioners did not invoice sub-contractor bills and material bills that the company had already paid. Obviously, such omissions to invoice costs timely, negatively affected the company's cash flow. Further, it was not clear to employees which of these paid bills had already been invoiced and which still needed to be invoiced. This often caused confusion among the practitioners. On lump sum contracts, there was no easy way for practitioners to identify how much budget was remaining for a certain line item of a project budget, or whether the budget already had been exceeded. In summary, independent from the contract type, it was not an easy task to get an overview about cash flow activities on each of the firm's ongoing projects. This missing possibility to access ongoing cash flow information made it hard for the company's practitioners to manage and control construction operations on each of the firm's projects. The employees explicitly raised this issue a number of times during our research effort and mentioned that they would benefit from an information system that would allow them easy and timely access to cash flow information.

Hence, we decided to evaluate a number of existing financial cost applications in a first technology implementation effort to determine whether one of them would offer the needed functionalities. We first tested the cost accounting application that the company used for their tax reporting. However, in line with the introductory claim of this paper, this cognitively developed general purpose application did not provide the required functionalities to support the financial decision making process as it failed to integrate with the existing language and decision making concepts present at the company. The main problem was that the applications did not support the categorization of cost information on a project basis. It was only able to display data about all projects in its database or to filter data according to specific temporary periods and, thus, a quick and easy way to get an overview about cash flow activities on a single project or about all active projects was not possible. Another problem that existed during data entry was that the application allowed for the definition of projects, but it did not allow for the easy definition of several budget line items for each of these projects. In addition to the functional shortcomings of the tested application to track information on a project and budget item level, it also lacked the user friendliness that is necessary so that non-accountants are able to use the software. It did not offer the possibility to easily enter data or visualize cash flow activities on a project to project basis. Further, it did not offer the easy functionality to track which paid bills had already been invoiced to the client and which still needed to be invoiced.

After evaluating the situation on the project according to the outcomes of the ethnographic observation, we decided together with the practitioners to install and set up a number of other general purpose accounting applications to test whether they would offer the required functionality. During an evaluation phase, we then tried to input data from two projects into these applications and tried to use them to improve the financial decision making. As expected, however, none of these other general purpose applications supported the specific features that the company's professionals requested as they did not integrate well with the local *cognitive categories*.

Due to the shortcoming of the existing general purpose solutions, we decided to develop new cost accounting software from scratch. After the development of an early prototype, following the action research methodology, we immediately implemented this early version of the system to test it using real world data from two projects parallel to the company's ongoing work processes. Consecutively, we adjusted the software during a number of ethnographic-action research cycles and practitioners were able to improve their financial decision making on the two projects showing the practical *utility* of the developed solution. However, despite the practitioners naming financial decision making as the main problem they face early on, they did never use the system for tracking cost information for other than the two test projects. In discussions with the practitioners it became clear that they did not take the time to try using the software. In the end, looking at this research effort from a pragmatic angle we can conclude that for this company the practical utility of a financial decision support system, even of one that is adjusted to the work processes with action research is low. This research is, therefore, a good example for fallibilism and how our reasonable beliefs that we arrived at the outset of this research effort through testing and experimentation in practice can turn out to be false at any time.

Improve the ongoing quality improvement of asphalt paving road construction operations

Within the construction industry the branch of asphalt road construction is a domain on its own. The firms apply equipment specific for paving and for compaction of the Hot Mix Asphalt (HMA). Paving crews which work as autonomous teams perform the work. These crews, each with their own set of equipment, travel from site to site seldom spending time at the base location of their construction firm. The amount of formal training is limited and in almost all cases the crew members have learnt their skills by training on the job through trial-and-error, copy cat and mimicking experienced crew members, whilst only being partly supervised. As a consequence each of these crews develops their own set of routines and practices.

During the construction of asphalt roads the compaction of a newly paved HMA mat is one of the most critical components of the overall paving process. On the one hand, freshly laid HMA is too hot for immediate compaction and HMA roller operators need to wait for some time with compaction to not overstress the material and cause irreparable damage. On the other hand, once the HMA is too cold, the material is too stiff and the rolling operations will have little effect on the compaction grade of the HMA. The roller operator has to work within a temporal temperature window during which they need to roll over every spot of the road surface a number of times. Operators need to memorize where they have been before, and keep track of the movements of their colleagues. Additionally, the available temperature window for compaction varies according to the HMA type and the local weather conditions. In summary, although the compaction processes appears rather simple and straightforward, it is a task requiring skill and knowledge on the part of the operator (Roberts et al., 1996).

To assist operators and at the same time improve productivity, there are several industry-aided research efforts for the development of state-of-the-art technologies for measuring the temperature of the asphalt, and for real-time locating and positioning systems to support asphalting operations. Equipment manufacturers have cognitively developed and installed several new instruments on HMA paving equipment to assist the paving and compaction process. Roller compactors are now equipped, for example, with GPS receivers, on-board computers, and infrared thermometers. Further, devices measuring the energy response of vibrating roller drums are introduced to allow for "intelligent" compaction[1]. Information available to crew members before rolling include details about the area to be rolled, the GPS position of the machine, and the road's current state of compaction. Using this information, technologies exist that calculate recommendations about the maximum and minimum compaction window temperatures, about the required rolling speed, and about the required minimum number of passes. During rolling activities, several displays installed on the roller equipment provide the operators with immediate information about the number of compaction passes they already completed, the actual roller speed, and the surface temperature.

Whereas manufacturers insisted that these instruments are useful to the operators, a series of structured interviews conducted with paver-, screed- and roller operators showed that crew members hardly make use of these available technologies and, hence, their pragmatic utility is low. For example, whilst all operators showed an awareness of the importance of the cooling process of the asphalt during compaction, most operators that had temperature measurement tools at their disposal did not use them and suggested during interviews that they could do without them. Moreover, whilst indicating that they used prescribed roller patterns, operators pointed out that they did not keep track of the number of compaction passes nor did they use the available technologies to do so during rolling. As a reason for not using the new technologies, operators indicated that they did not understand most of the new technologies that they found the input parameters much too complicated, and they questioned the relevance of the input and output information. Additionally, operators stated that they cannot cope with the amount of information to process during the, already in itself difficult, asphalt paving and compaction process.

To overcome these problems, we started an ongoing action research effort with a number of HMA contractors to make the operators tacit knowledge, heuristics, and routines explicit and to accordingly introduce new technologies with the aim to support

[1] Amongst scientists, practitioners and manufacturers debate is still ongoing whether this "Intelligent Compaction" really measures compaction rate (ref…)

the craftsmanship of the operators rather than to substitute it. To do so, we worked closely together with the paving crews, stimulating discussions about the variability within and among crews and asking crew members to try to verbalise their operational heuristics.

The first step of this action research was a combined effort of three Master students. The first student conducted twenty-plus in-depth on-site interviews on the use of new technologies. During these interviews the student was able to collect many anecdotal examples of how heuristics that HMA paving operators used during paving operations. For example, during interviews roller operators stated that one of the main clues that they used to understand the temperature of the asphalt were changes in the “surface colour” of the HMA. Amazingly, they could not explain what the colour differences signified, or how they were caused[2]. The second student worked embedded in two paving crews for over six months to map the crews learning strategies. It showed that the crews are hardly reflective, have a strong group culture of toughness, and only learn accidentally. The third student focussed on the way the crews deal with irregularities in the HMA supply given that the logistics are scheduled based on experience. The crews affected by irregularities complain about the logistics and how it negatively affects the quality and productivity. Yet, they stay complaisant and do not take preventive action.

Based on the results of these three MSc projects, we developed a full scale data collection strategy across a number of projects. On the first project, at the start of the effort, a technology manager from the company and three researchers worked closely with the asphalt team. They spent two nights on a highway road construction project, measuring and monitoring the HMA paving and compaction work processes using infrared and GPS technologies.

After this data collection effort, we, in close collaboration with practitioners developed a first set of data visualizations:

[2] Confronted with this enigma of “colour shift” the researchers started approaching several other experts inquiring what that phenomenon was. Eventually one of the “lecturers” of the operator training school explained that this shift had to do with the change of consistency of “film of bitumen” on the surface (from shiny black to dullish brown).

- “Temperature Contour Plots” showed the variability in temperature homogeneity at the time of asphalt laying,
- “Compaction Contour Plots” showing how often roller operators compacted each of the areas of the asphalted road, and
- Animations that provided us with explicit evidence of the co-operation between pavers and compaction rollers.

To access the utility of these visualizations, we conducted a number of workshops with the paving crews to test how well the visualizations work to explicit the tacit knowledge of the operators during a dialogue between researcher and practitioner (Simpson et al. 2004). During the workshops, the operators mentioned that by using the visualizations they are able to better understand the importance of asphalt temperature and compaction. This triggered a critical discussion about their asphalt paving exercise. In particular, the operators agreed that they did not pay much attention to asphalt temperature during the compaction operation, that they did not keep track of the number of passes completed during rolling, and that they did not know what their fellow roller operators role was in the process. Instead of using temperature information, they used “visual assessment of distance to the paver” to judge whether the HMA was cool enough to compact. Hence, in summary, next to assessing the utility of the visualizations, the workshops also enabled us to start a critical, but also very creative discussion about the crew’s operational practices and about further improvements for the visualizations, most importantly, the need for a visualization of the asphalt cooling process and the visualizations of the asphalt compaction grade. The operators suggested that these two measurements would allow them to make the relationship between asphalt temperature and the time available for compaction explicit. Operators also suggested that it might be more helpful to understand their operations if visualizations are available more timely after the asphalting exercise because they would be easier able to remember specific details.

In a next iteration of the action research cycle, we, consecutively, started to focus on the issues that we identified together with the practitioners during the workshops. In a first step, we implemented a second monitoring exercise with one of the crews that we conducted a workshop with earlier. We introduced continuous temperature measurements using an infrared camera mounted on the back of the paver to accurately capture the surface temperature of the asphalt in real-time. We also measured cooling rates of the HMA using a combination of digital thermometers to measure in-asphalt temperature and infrared cameras to measure the asphalt's surface temperature. We also measured the HMA density after each compaction pass to further study the compaction behaviour of the HMA. Finally, we also kept ethnographic event logs to track the operational crew behaviour.

In discussions with the crew members during this second exercise we were also already able to assess the utility of the workshops and of our first action research cycle. The operators reported that they used the explicit knowledge that they gained during the workshop and tried to improve the HMA paving operations accordingly. The utility was further indicated by a comparison of the two projects' Compaction Contour Plots that showed the temperature homogeneity to be significantly improved during the second exercise. However, in discussions with the crew members after the exercise we were again able to identify a number of possible areas of improvement. For example, the temperature segregation remained a problem in some parts of the paved asphalt or while roller operators appeared to work in a complimentary manner the Compaction Contour Plots still showed significant variability between different areas of the road.

As the second exercise showed that our visualizations helped the crew to understand their operations, we started to develop a visualization tool for Hot Mix Asphalt (HMA) paving operations. The tool consistently visualizes data collected with advanced GPS and temperature devices according to the outcomes of the previous action research. We, therefore, hope that the tool visualizes data collected during HMA paving operations in a format that is meaningful and understandable for the people involved in the paving process. The tool collects data from different sources, converts, calibrates, filters, structures and stores them in a database. Through offering display options and a time slider, the tool makes it possible to monitor and analyze the initial temperatures and the cooling processes at different points in time. As such, it provides insights into the physical characteristics of the material, into consistency of the paving operations and into potential quality issues that are easily understandable by HMA paving operators.

Implications

If nothing more, the paper shows that the three action research projects followed the five basic maxims of pragmatic enquiry (Table 1). In this way, we make the roots of the action research methodology in the pragmatic research philosophy explicit. We show that on the projects the action researchers *took a look* to understand local *cognitive concepts* of practitioners. Further, we show that the action researchers then developed and *iteratively* improved technologies by assessing their *utility* through a direct implementation in the practical setting. Following Macbeth's advice (2007) to conduct pragmatic inquiry, the evidence from the three cases also shows that the action research methodology allowed us to slowly develop an understanding of local practices in a bottom up approach in close collaboration with organizational members. This understanding, in turn, helped us to represent organizational problems, abstract them into internal systems to develop solutions to stabilize encountered problems. We also show that on the cases previous efforts to stabilize problems using the cognitive mode of inquiry failed while action research was, at least, partially able to improve the practice of the complex organizations under study. In this way, the paper also provides evidence that the action research method allows researchers to find solutions that work in complex organizations.

We belief that this explicit link of action research with its origins in the pragmatic research philosophy can help action researchers to conduct better research and to, in turn, develop better concepts and technologies to improve complex organizations. In detail, we show that ethnographic and participatory efforts to *take a look* enables

Table 1: Summary of the Cases

Pragmatic Maxim	Case 1: 3D	Case 2: Cost	Case 3: Asphalt
Problems with cognitive solution	Practitioners did not understand the required 3D model's detail level and structure for meaningful clash detection. The cognitive solution did not provide any support with this issue because it was only developed and tested using much simpler designs. A meaningful automated detection of clashes was not possible.	The cost information that an existing financial information system provided was not reliable, up to date, and its categorization of information was inadequate to support financial decision making.	Cognitive solutions to visualize information to understand information during asphalt paving operations did not provide any support to practitioners. These visualizations either visualized the wrong information, or they visualize information in a form that practitioners cannot understand.
Taking a look approach	Participatory case study research on two consecutive hospital construction projects.	Participatory case study research observing the financial decision making work with a house builder company in California.	- In-depth on site ethnographic interviews with operators - participatory research on two road construction projects - workshops with paving crews to explicate the operational strategies
Identified Language/Concepts representing the internal system	Content that needed to be presented within the 3D model including the important parts of the design according to the experience of the projects' participants.	Categorization that the practitioners used to implicitly make financial decisions without the existing cost system.	- compaction contour plots - temperature contour plots - animations of equipment movements
Utility	The new internal system enabled the use of the 3D models on the project. Staff hours and financial savings compared with the initial estimated values became significantly lower.	The new internal system enabled the company's professionals to understand the finances of the company better on two exemplary projects. This allowed them to make better financial decisions. However, most of the professionals did not take the time to look into the system and thus the overall value of supporting the financial decision making of the professionals is questionable.	The visualizations made operational behaviour explicit and understandable and improved the operations of one paving crew.
Fallibilism	On the second project, the implementation of the initially developed technology failed, because the design practitioners did not work co-located within one office. The management of integrating the different party's sub-designs into the overall 3D model again exceeded the practitioners' cognitive limits.	The professionals in the company never used the system beyond managing the two initial projects.	The developed visualizations lost much of their value, because it took too long to create them.
Iterative adjustment	Development of a formal work process for 3D modeling supported by a custom tailored collaboration software.	Iterative adjustment of concepts and decision support system throughout the ethnographic action research effort.	Adjusted data collection methods, data visualizations, practitioner workshops, and the integrated process of data collection, visualization, and workshops. Supported the revised process with custom tailored software.

researchers to understand explicit and tacit knowledge of organizational members. We, further, show how this understanding allows researchers to develop concepts and technologies that closely integrate with the local *cognitive concepts* of the organization under study. The direct implementation of these concepts and technologies to assess their practical *utility* and their *iterative* development further allows researchers to integrate organizational knowledge and organizational knowing. Only this integration allows organizational improvement and organizational learning (Cook & Brown, 1999). In summary, accounting explicitly for the five pragmatic maxims during action research efforts, allows researchers to enable organizational members to combine their tacit and explicit knowledge to develop new organizational knowledge. At least, it helped us to do so during our action research efforts.

The paper also draws attention to two pragmatic inquiry maxims that other action researchers, to the best of our knowledge, have not addressed empirically so far: the maxims of iterative development and fallibility. The notion of fallibilism can help researchers during their action research efforts. Action researchers develop new organizational technologies in a slow, iterative, and bottom-up approach. During each iteration, they account for the fallibilism of their developed technology by directly implementing the technology in practice to test for its utility. This provides them with an early warning system – in case the practical utility of the developed technology is low they can still change the direction of their research. Cognitive researchers do not have this possibility and always face the risk that significant research projects conducted over several years will only have a low utility in practice. However, action researchers, so far, have not reported on iterations that failed in their research despite the fact that such reports on failed efforts also advance the theoretical organizational knowledge. We, therefore, suggest that action researchers in the future not only report about their successful iterations, but also provide a critical evaluation of their unsuccessful iterations similar to our description in case two. This will allow future action researcher, but also organizations, to avoid repeating the mistakes that other action researchers have committed in the past. Additionally, the notion of fallibilism helps researchers to challenge the set way of practitioners. If practitioners start accounting for the possibility that any previous developed technology can fail, helps practitioners to realize that some of the technologies they assume tacitly to improve their productivity, do not, or can be improved upon. This realization can start very fruitful action research cycles in which the practitioners together with the researchers are able to overcome some of their pressing and inherent organizational problems.

Conclusion

This paper made the pragmatic roots of the action research methodology explicit by showing that the five maxims of pragmatic inquiry are at the heart of the action research methodology. The paper empirically illustrates how these maxims influenced three engineering action research efforts. By making the pragmatic roots of the action research methodology explicit, the paper derives a number of direct implications that can support researchers with designing and conducting action research efforts.

Hence, the paper shows that action research with its pragmatic basis is well suited to inform engineering research in complex and frequently changing environments. The action research methodology is poised to help engineering organizations to redesign themselves. Further, action research with its potential to improve complex engineering organizations within a direct practical and applied context can help to close the drift between engineering research and engineering practice.

The paper also integrates into two long lasting pragmatic discussions. First, philosophers have questioned whether the pragmatic mode of inquiry is applicable to all fields of inquiry (Macbeth 2007: 181). While the paper, of course, cannot answer this question in its entirety it, nevertheless, shows that the maxims of pragmatic inquiry are very useful in the domain of engineering management research. Second, the findings of the paper integrate well into a long lasting discussion between proponents of two opposed versions of the philosophy (Rescher 2000: chapter 2). On one hand, the right view of pragmatism is concerned with proposing and legitimatizing objective ideas using the pragmatic mode of inquiry. On the other hand, a left, deconstructive view of pragmatism is concerned with de-legitimatizing objective ideas and previous research results. Action research methodology draws on both views at the same time and, thereby, shows the value of the pragmatist philosophy in its entirety. Within each of the iterations, the methodology uses a left approach to de-legitimatize the current practices of the practitioners. In this way, researchers can challenge the “set way” of how practitioners do things. These challenges trigger reflective thinking about the work practices that foster the creative social dialogues that are required for a fruitful, productive, and satisfying ongoing continuous improvement within a community of inquiry (Mead cited by Rescher 2000: 30). On the other hand, the methodology uses a right approach to pragmatism by trying to iteratively and continuously improve the work processes on one engineering project and across several engineering projects. Whether the ongoing improvement of technologies will, in line with Peirce initial theses (Rescher 2000: 9), converge evolutionary to a final truth is questionable. Nevertheless, all action research efforts should strive as best as possible to improve technologies with the hope to reach a state that is as close to the optimal as possible.

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