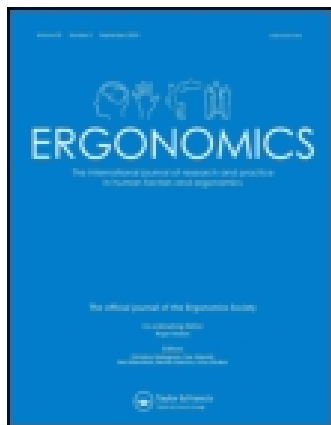


This article was downloaded by: [74.15.108.236]

On: 04 March 2015, At: 14:06

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Ergonomics

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/terg20>

An ergonomics action research demonstration: integrating human factors into assembly design processes

J. Village^a, M. Greig^a, F. Salustri^a, S. Zolfaghari^a & W.P. Neumann^a

^a Human Factors Engineering Lab, Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, Canada

Published online: 17 Jul 2014.



CrossMark

[Click for updates](#)

To cite this article: J. Village, M. Greig, F. Salustri, S. Zolfaghari & W.P. Neumann (2014) An ergonomics action research demonstration: integrating human factors into assembly design processes, *Ergonomics*, 57:10, 1574-1589, DOI: [10.1080/00140139.2014.938128](https://doi.org/10.1080/00140139.2014.938128)

To link to this article: <http://dx.doi.org/10.1080/00140139.2014.938128>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

An ergonomics action research demonstration: integrating human factors into assembly design processes

J. Village*, M. Greig, F. Salustri, S. Zolfaghari and W.P. Neumann

Human Factors Engineering Lab, Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, Canada

(Received 10 December 2013; accepted 19 June 2014)

In action research (AR), the researcher participates ‘in’ the actions in an organisation, while simultaneously reflecting ‘on’ the actions to promote learning for both the organisation and the researchers. This paper demonstrates a longitudinal AR collaboration with an electronics manufacturing firm where the goal was to improve the organisation’s ability to integrate human factors (HF) proactively into their design processes. During the three-year collaboration, all meetings, workshops, interviews and reflections were digitally recorded and qualitatively analysed to inform new ‘actions’. By the end of the collaboration, HF tools with targets and sign-off by the HF specialist were integrated into several stages of the design process, and engineers were held accountable for meeting the HF targets. We conclude that the AR approach combined with targeting multiple initiatives at different stages of the design process helped the organisation find ways to integrate HF into their processes in a sustainable way.

Practitioner Summary: Researchers acted as a catalyst to help integrate HF into the engineering design process in a sustainable way. This paper demonstrates how an AR approach can help achieve HF integration, the benefits of using a reflective stance and one method for reporting an AR study.

Keywords: macro-ergonomics; action research; human factors; ergonomics; design

1. Introduction and objective

In action research (AR), researchers work with organisations to solve real-world problems by influencing solution development from an embedded position in the organisation. The goal is not solving a problem ‘for’ others, but ‘with’ others in joint learning (Ottosson 2003). It is a non-experimental, experiential approach that, when supported with theory, or by theory development, can provide both practical new approaches and transferable learning. The cornerstone of the AR approach is continuous reflection on the action to inform the next set of actions.

In the first paper of this journal’s two-part ‘Ergonomics Action Research’ series, collaborative AR methodological approaches were recommended to facilitate learning about ‘how’ to implement human factors (HF) (ergonomics) in organisations (Neumann, Dixon, and Ekman 2012). Although common in other areas of research, such as business management, there are few AR demonstrations in the ergonomics/HF literature. The AR approach differs from other methodological approaches, for example, in how the researcher participates with the organisation, how scientific literature is used throughout the intervention and how data are collected and analysed concurrently to help inform the next stages of action. Because of these differences, reporting AR studies in traditional scientific journals is challenging since the methods and results are difficult to disentangle. To encourage this methodological approach in ergonomics, there is therefore a need for more examples of how to conduct and communicate AR findings for both researchers and practitioners.

In the second ergonomics AR paper, a framework was suggested to guide practitioners or researchers who work with organisations to develop proactive ergonomics (HF) capabilities within the manufacturing design process to improve both work performance and worker well-being (Neumann and Village 2012). The framework essentially suggests that HF integration is unlike a planned intervention since it must be moulded to suit the organisation, its design processes and the political and cultural context. The framework recommends a macro-ergonomics approach with multiple concurrent initiatives aimed at each level of the design process (i.e. strategic decision-making, product design, design of the production assembly and operations). The empirical data to demonstrate the application of the macro-ergonomic approach discussed by Neumann and Village (2012) have yet to be reported in the literature.

This paper attempts to fill the gaps both in lack of reporting of ergonomics AR studies and in lack of macro-ergonomic projects aimed at integrating HF into production systems design. The goal of this paper, therefore, is to present a longitudinal case study involving an ergonomics AR collaboration between an electronics manufacturer and researchers to

*Corresponding author. Email: jvillage@ryerson.ca

integrate HF proactively into design processes. The purposes of this paper specifically are to:

- demonstrate one approach for conducting and communicating an AR study in ergonomics;
- illustrate how AR can lead to a deep understanding of ‘how’ to integrate HF into production systems design; and
- demonstrate the benefits for both researchers and practitioners in adopting a reflective stance in their HF work.

1.1 Background

AR has a long history of use in fields such as education and teaching (Davis 2007; Whitehead 2009), community health care and social change (Balcazar et al. 2004; Boothroyd, Fawcett, and Foster-Fishman 2004; Suarez-Balcazar et al. 2004) and business management (Bamford and Forrester 2003; Friedman and Rogers 2009; Lander and Liker 2007; Zink, Steimle, and Schroder 2008). However, as Neumann, Dixon, and Ekman (2012) point out, the limited application of AR in HF and ergonomics may in part be due to the perceived ‘unscientific’ nature of the methodology. While some suggest that AR is an imprecise form of inquiry, it can be argued that these are exactly the qualities needed to more fully understand the realities of working with people in complex situations such as macro-level organisational change (Davis 2007; Neumann, Dixon, and Ekman 2012). Observing change from an ‘embedded’ position within an organisation offers unique insights, difficult to obtain otherwise. In fact, in health care practice and policy in the UK, AR is considered a welcomed approach over randomised control trials as it can provide a larger understanding of issues and attitudes, rather than ‘testing’ of predetermined approaches (Meyer 2000).

Academic integrity of AR studies depends on both the capability of solving practical HF problems and at the same time rigorously scrutinising the experiences from the field collaboration in order to communicate the research findings (Levin 2012). This is no easy task, as Levin (2012) points out, as it requires mastering relevant and significant scientific technical knowledge, knowing how to run participative processes, commanding strategic and political skills, and being capable of reflecting on ethical and moral challenges in the research process. Ottosson (2003) suggests that despite the extra demands, the findings can be put into practice more quickly, resulting in better and deeper learning for those involved. The balance of acting and reflecting as a researcher promotes ongoing and experiential ‘testing’ of various approaches *in vivo* in the organisation and promotes ‘learning by interaction’ – both for researcher and practitioner – about what works and what does not work for the organisation (Levin 2012; Neumann, Dixon, and Ekman 2012; Seim, Broberg, and Anderson 2012). This case study will demonstrate the acting and reflecting in the AR approach and show how that led to a deep understanding about ways to integrate HF into design processes.

The way in which AR is conducted does not lend itself to typical linear scientific reporting of methods, results and conclusions (Davis 2007; Fisher and Phelps 2006). As will be demonstrated, instead of being an observer, the researcher participates ‘in’ and directly influences the collection, interpretation and outcomes of the research. Data are collected and analysed concurrently since results are needed to inform the next set of actions. And as will be shown, theory and scientific literature are interwoven as helpful throughout the study. This entangling of methods and results in AR therefore requires somewhat unconventional communication approaches. Some communicate AR using a case study narrative or storytelling approach (Fisher and Phelps 2006). Some authors use different voices such as the ‘third person’ to tell the facts of what happened, the ‘reflective practitioner’ to discuss the interplay between researcher and practitioner, and the ‘critical reflector’ which is the commentary on the reflective practitioner (Fisher and Phelps 2006). Qualitative data from AR studies can also be further analysed for development of theory (Friedman and Rogers 2009; Raymer 2009; Whitehead 2009). Friedman and Rogers (2009) suggest that meaningful change requires good theory and the development of good theory requires attempts to change the world. In particular, AR with its ‘action’ and process focus seems well positioned to develop grounded theory approaches with the data (Bamford and Forrester 2003; Dick, Stringer, and Huxham 2009; Poonamallee 2009).

In this paper, we have chosen a non-traditional reporting format to demonstrate the AR approach, and to show how AR was helpful in this collaboration for integrating HF into design processes. Instead of ‘methods’ and ‘results’ sections, we first describe the AR approach and its application in this collaboration under subheadings that give the context. We describe the case study organisation, the university–industry collaboration, the goal of the collaboration, the changing role of the researchers and the industry partners, the roles of both scientific literature and theory in this study, and how data were collected and analysed. We then describe the three phases of the collaboration that emerged, which we called:

1. gathering information;
2. seeking the HF fit; and
3. HF specialists acclimate and strategically align to engineering.

The description of the phases will show how both the actions taken and the researcher reflections proceeded over time in this collaboration in three non-linear iterative cycles like an unfolding narrative, or the story of changes in practices, with the researcher as co-participant (Fisher and Phelps 2006). Stages overlap and change is happening throughout and embedded in the research process (Davis 2007). This shows the intertwining of research and action, theory use and theory development, and learning and adaptation as a collaboration proceeds. Cycles are interdependent on actions and learning from previous cycles in a process described by Fisher and Phelps (2006) as mutual change and inquiry.

2. Demonstration of how ergonomics action research was conducted in this collaboration

2.1 Doing action research

In the AR approach, it is the responsibility of researchers and practitioners together to define the plan, carry out the initiatives and monitor what is helping or not helping achieve the goal in the organisation. When a framework for change is not well known, Seim, Broberg, and Anderson (2012) suggest 'learning by interaction', or 'situational learning', which means that both parties bring knowledge to the collaboration and both learn together from the interaction. It is generally considered the responsibility of the researcher to then analyse and communicate what is learned in the context of scientific literature and theories in ways that other organisations and researchers can benefit from.

The approach used in this study was based on the iterative AR model reported by Meyer (2000), and shown in Figure 1, as 'plan', 'act', 'observe' and 'reflect'. This model assisted researchers with ensuring that each action or initiative was part of an overall plan. It also reminded researchers, who are part of the action, that they had to frequently disengage from the actions sufficiently to observe the effects and reflect on what was working and not working as the AR proceeded. While depicted as a cycle with distinct stages, in reality the stages overlap, are ongoing and are non-linear, which can be depicted more like a spiral over time.

Questions, such as those in Table 1, were helpful for both researchers and practitioners in each of the AR stages as the collaboration proceeded.

2.2 Description of case study organisation

The case study organisation designs, manufactures and assembles hand-held electronic devices. At initiation of the collaboration, it employed approximately 20,000 people worldwide. The collaboration focused on the new product realisation site in Southern Ontario since this is where the parts and assembly production process are designed, prior to being outsourced to high-volume production sites. The site realises multiple new products yearly, offering opportunity during the multi-year collaboration of participation in repeated design cycles.

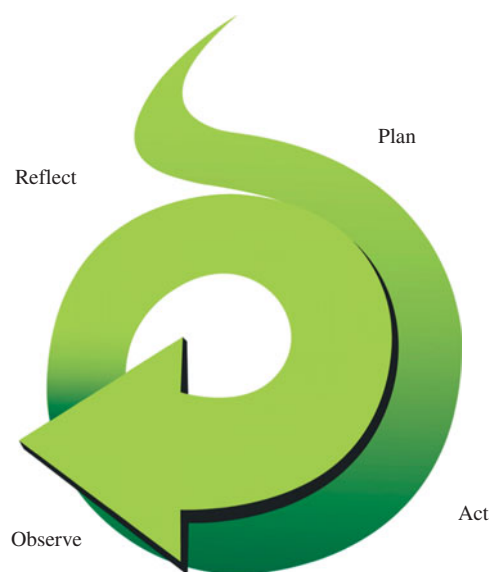


Figure 1. Action research cycle and spirals (adapted from Meyer 2000).

Table 1. Sample questions for the researcher/practitioner to consider at each action research stage.

Stage	Sample questions
Plan	What is the issue or challenge at this stage? What do ergonomics practice and the researchers' experience suggest would work best at this stage? What does the scientific literature contribute? Who should be involved? How can this be done? What role should the researcher take?
Act	What type of action would work best? When, where and how should the action occur? How will the action be recorded, documented or assessed?
Observe	What was the response to the action? What else is going on in the organisation that affects the action?
Reflect	What would have improved the action? What hindered the action? How can the scientific literature or theories provide insight? What are the next steps or strategies?

2.3 Description of the university–industry collaboration

The collaboration began with a memo of understanding between the organisation's occupational health and safety (OH&S) manager, the director of engineering and the University's principal investigator in 2008. Two research students in the Human Factors Engineering Lab of the Department of Mechanical and Industrial Engineering started in the fall of 2009 followed by two more in the fall 2010. Students had backgrounds either in industrial engineering or HF. Four Ergonomists and an Ergonomics Manager from the organisation participated in the collaboration at various times, and over the three years 70 engineers and managers were involved in one or more aspects of the collaboration. For confidentiality, we use 'HFS' (Human Factors Specialist) to describe the HF activities of company HFS, regardless of whether there were one or more HFSs involved. We use the term 'HFS team' to describe the combined company HFS and researchers.

2.4 Goal of collaboration

The goal of the collaboration was to help the organisation increase its capabilities to integrate HF early in design processes with the underlying assumption that doing so would improve both worker health and business performance. The starting point was the broad framework by Neumann and Village (2012) described in the introduction to guide integration of HF at multiple levels in the design process. As the collaboration proceeded, the researchers worked interactively with the industry team to look for opportunities or projects that would lead to improved HF integration in a way that would be sustainable for the organisation. The approach is participatory and facilitates co-learning for both industry participants and researchers. However, in this collaboration, we were seeking participation with HFS and manufacturing engineers because of their role in designing the production system. Instead of physical changes to equipment or workstations, we were seeking changes to their design processes.

2.5 The evolving role of researchers in an AR collaboration

In AR, the researcher may take on a variety of roles, depending on circumstances. Since the researcher is an active participant 'in' the intervention (rather than collecting data 'about' the intervention), and since the bias and experience of the researcher is relevant to qualitative interpretation of the data, researcher disclosure is important in communicating findings (Fisher and Phelps 2006). In this study, the researcher (first author) is a certified professional ergonomist with more than 25 years of experience practising ergonomics and conducting applied research to reduce work-related injuries. She has extensive experience working with engineering teams and designers and strongly supports the goal of implementing HF early in design processes. This AR case study formed part of her PhD dissertation in industrial engineering.

The researchers' role was informed in this study by reviews of organisational change (Palmer and Dunford 2008), and AR literature (especially Patton 2011). Palmer and Dunford (2008) suggest six potential roles, based on differing organisational theories and ontological assumptions: directing, navigating, care-taking (when controlling the change), coaching, interpreting and nurturing (when shaping the change). Researchers adapted their facilitation role with HFS and engineers according to the type of change being implemented (intended, partially intended or unintended), the capabilities of the HFS, the stage of change in the organisation and other external factors.

As applied in this collaboration, during the first phase of gathering information, researchers helped the HFS with navigation to understand design processes and the people involved and to create a desire for change (Palmer and Dunford 2008). When needing to get the attention of engineers and senior managers during the second and third phase, there was some directing of initiatives (where researchers helped HFS to demonstrate HF), coaching for the HFS to purposely build their skills and interpreting to help the HFS and engineers make sense of interactions and continue to promote the HF agenda. In the latter phase as company HFSs were becoming more integrated with engineers, the researchers' role shifted to one of nurturing of the HFS to facilitate sustained ability to plan, act, observe and reflect without researcher participation. Patton (2011) describes the researchers' role in AR as being active, reactive, interactive and adaptive – thus changing as needed. This mode of operation recognises that roles and actions are not planned and linear in AR.

2.6 *The role of industry partners in an AR collaboration*

The role of industry partners in AR can involve complete collaboration in all aspects of planning, acting, data collection and analysis, and reporting of results (Huxam and Vangen 2003; Meyer 2000). In this AR study, the extent of collaboration increased over the three years. From the beginning, the HFSs were the focal point of the collaboration since we were encouraging new practices in proactive HF and more interaction with engineers. While always involving and consulting the HFS, some initiatives in the first two phases were conducted by university researchers with little participation from engineers in the organisation. However, all resulting data were presented, discussed and verified with all industry partners. The formation of a steering committee with engineering management, and especially the appointment of an engineering project manager increased collaboration and co-learning during the second and third phase. At the end of the third phase, industry partners were actively planning, collecting and interpreting data. They also communicated findings to their peers at conferences, suggesting a higher level of involvement and ownership. In the final phase, HF activities were initiated, carried out and documented entirely by the organisation, with researchers acting as observers. Organisational participants also incorporated a reflective stance by recording meetings and reviewing these recordings afterwards.

2.7 *The role of scientific literature in action research*

In traditional intervention studies the scientific literature is reviewed initially to inform methods, then later when comparing results with other studies. In AR, scientific literature is accessed and reviewed throughout the intervention. Reflecting on the actions in the case study within the larger context of scientific literature ensures ongoing learning and application of new knowledge to the intended changes (Nielsen, Svensson, and Svensson 2006). In essence, research validity in AR has been described as systematically alternating between performing 'on-stage' and reflecting critically with the literature 'back-stage' (Nielsen, Svensson, and Svensson 2006).

In this AR study, the first phase was informed by studies of organisational change, facilitators and barriers of HF integration, socio-technical systems theory, macro-ergonomics and complexity theory. In the second phase, researchers reviewed literature pertaining to strategic goal setting (such as cognitive mapping), and literature discussing links between quality, fatigue, performance and assembly design. The intent was to provide the industry partners with evidence as to how HF benefits worker performance. In the third phase where the focus was on adapting engineering tools for HF, researchers reviewed literature pertaining to business process improvement and engineering tools to look for relevant examples.

2.8 *The role of theory in action research*

As with the scientific literature, theory is used in AR throughout the study to frame actions, help interpret actions or to help reflect on actions for the research community. The theoretical underpinning in this study lies in complexity theory (Mingers and White 2010). In contrast to earlier theories suggesting organisations are static and that change involves unfreezing and refreezing, complexity recognises features of instability, disequilibrium, sudden change and complex behaviour. Complex systems have a large number of interacting and interdependent elements in which there is self-organising and emergent behaviours that generate learning, evolution and development (Patton 2011). The complexity sciences improve understanding of the behaviours of social and organisational systems when faced with increasing uncertainty both internally and externally. In the partner organisation we encountered manifestations of complexity, described by Mathews, White, and Long (1999), including major shifts in organisational policy and product development, employee turnover and management succession. Such 'high-velocity' industries have short product cycles, a rapidly shifting competitive landscape and a need for rapid and relentless continuous change as their crucial capability for survival (Brown and Eisenhardt 1997). Since they are 'constantly reinventing' themselves, change is not seen as negative, but continuous, dynamic and opportunistic. Complexity theory helped the researchers in this study frame their observations. Rather than expecting small incremental

improvements, and 'planned' increases in HF application, researchers were instead aware of and anticipated uncertainties, dynamic shifts in HF application, turning points and unpredicted adaptive behaviour (learning).

2.9 How data were collected and analysed

In AR, data collection is conducted concurrently with data analysis since actions, observations and reflections inform the next cycle of planning in the study. Generally, qualitative data are sought in AR studies, but occasionally there may be a combination of qualitative and quantitative data.

In this collaboration, qualitative data were collected from mid-2010 to mid-2013. To substantiate findings, data were triangulated from three sources: tracking of *actions/interactions*, review of organisational *documentation* and collection of participant and researcher *reflections*. In-person interactions were planned approximately weekly with electronic interactions (web-ex and teleconference) between site visits. For each meeting or focus group, researchers helped prepare the HFS beforehand, participated during the event and reflected with them afterwards to promote co-learning and plan the next actions. *Actions/interactions* were collected with a tracking log and through note-taking. The log was used to document, for example, meetings, interviews and workshops. The log included people involved, type of interaction, topic and time. Notes taken during and after every interaction documented items discussed, observations and actions taken.

Documentation from within the organisation was used to plan and track action and to support observations. It included, for example, meeting minutes, product designs, tooling procurement, assembly layouts, work instructions, manufacturing process documents and organisational charts. The HFS sought advice from researchers when preparing documentation pertaining to the collaboration.

Reflections were captured through informal discussions, group interactions and by formal interviews as follows:

- by documenting researcher 'impressions' as notes with each action/interaction entry;
- by asking participants (HFS, engineers and managers) to reflect after meeting or workshop interactions and taking notes or collecting email correspondence;
- with regular meetings with the HF manager and HF group to strategise;
- with semi-structured interviews with all participants annually in the fall of 2010, 2011 and 2012; and
- by researchers regularly reviewing transcriptions of events and discussing data at university research team meetings.

During all reflections, participants were asked in an open-ended way what is 'helping' with HF integration, and what is 'hindering'. They were asked to reflect on what could be done differently, and the next steps to forward the HF agenda. Reflections during interviews at the three points in time informed and facilitated the next phase of planning and action in the larger collaboration. All formal meetings, interviews and workshops were digitally recorded, transcribed and entered into NVivo software for qualitative analysis.

All data were qualitatively coded using a grounded theory approach (Strauss and Corbin 1990). An initial set of codes was developed to investigate facilitators and barriers to HF integration in design, based on specific literature: macro-ergonomics, organisational change, participatory ergonomics and developmental evaluation. As open coding proceeded, codes were added to the initial list as needed, and those not pertinent were discarded.

Using the set of coded data, several types of drawings and visualisation approaches were employed to assist with analysis and interpretation of the data, for example, memo-writing, developing timelines, developing a matrix for comparison of initiatives, drawing organisational influence diagrams and describing sequential stages of each initiative. While each of these informed the analysis of the data, in this paper we have chosen to report the findings using the AR model of Meyer (2000).

3. The three phases and HF changes in the AR collaboration

3.1 Overview

The collaboration will be described chronologically in three phases coinciding with the yearly reflective interviews with participants. Phases were named according to the dominant action in the phase as:

1. gathering information;
2. seeking the HF fit; and
3. HFSs acclimate and strategically align to engineering.

Table 2 provides an overview of the three-year-long phases, organised for discussion purposes using the AR model of plan, act, observe and reflect (shown in Figure 1). Describing the case study in this way helps communicate how the

Table 2. Description of the three case study phases over three-year period using the AR framework.

Plan	Act	Observe	Reflect
Phase 1. Gathering information (mid-2010–mid-2011)	Get 'into' organisation at multiple levels, work with those interested, gather information and look for multiple initiatives that would help with goal of HF integration	Gather information, e.g. current HF work, injury reports, workstation layout concerns, HF perceptions, HF metrics Map design process to find opportunities to integrate HF Interview participants about how best to integrate HF	Lack of senior management involvement outside OH&S or knowledge of HF and HFS HF needs repositioning HFS need to learn design and business processes Need for senior management steering committee for project HF needs to be aligned with strategic goals (quality) and CI HFS need to learn engineering processes, language and tools HF not visible, tangible and engineering-like – it is disconnected with little traction on ideas
Phase 2. Seeking the HF fit (mid-2011–mid-2012)	Engage more senior management in HF integration, get access to relevant initiatives to integrate HF and learn about company's strategic goals and how HF could help	Cognitive mapping to understand strategic goals and management perceptions of HF Access to some limited proactive engineering initiatives (e.g. HF pFMEA, discrete event simulation) Reflective interviews with committee regarding facilitators and barriers to HF integration	Management perceive HF related to fatigue, quality and systems design Attempts to 'push' HF into engineering get little traction Strategic goals shift and organisation focuses on new product realisation and continuous improvement (CI) Reorganisation – Senior Director leaves
Phase 3. HFS acclimate to engineering and align HF to strategic goals (mid-2012–mid-2013)	Be more visible, on the shop floor, demonstrate HF initiatives, show HF as a means to improve quality and reduce operator fatigue, engage more engineers, develop useful tools and metrics	HFS work on manufacturing floor with engineers to optimise next assembly cycle HFS moves to engineering department Adaptation of IE tools for HF Demonstration of usefulness of HF tools to improve assembly Senior Director adopts HF targets in assembly design stages	Lay-offs forcing realignment and refocus in organisation HFS needed to shift focus from injuries to business goals lack of HF tools for assembly Adapting IE tools leads to adoption of HF in process Senior Director adopting HF target ensures engineers consider HF HFS pulled into next product build ensuring process sustainability

methodology of observing and reflecting in turn influences the next phase of planning and action, and how the scientific literature and theory are woven throughout the study and inform the process.

3.2 Phase 1: gathering information

The initial plan was to get 'into' the organisation at as many organisational levels as possible, gather information and look for initiatives that would help integrate HF into multiple levels of the design processes. The main participants early in the collaboration were the manufacturing HFS, an industrial engineer and a manufacturing manager. The OH&S manager who helped initiate the collaboration left the organisation during the first year.

Activities to gather information focused on understanding the role and tasks performed by the HFS, identifying typical workstation and assembly concerns, reviewing worker injury data, gathering information about metrics driving business performance and potential HF metrics, and determining links to engineering groups or design processes. One student, through a series of interviews and workshops, developed a process map of the assembly design process to help the group understand the stages and decision gates. The map was then used in collaborative workshops with engineers and HFS to identify potential initiatives for integration of HF (see Lim et al. 2014, for details). In this way, the action (of producing the map and discussing HF initiatives) could lead to planning the next HF actions for integration in design processes. The map helped the HFS team and others realise the role of various departments in the design process, and potential overlap with HF considerations.

The observations from this phase illustrated that most of the HF work in production was reactive (after an injury or incident). With the HFS situated within the OH&S department and reporting through facilities, there were very few links to engineering groups. The HFSs not only were physically separated from engineering, but also had few other connections to engineering personnel and none of the engineering design processes involved HF. The HFS expressed frustration at not knowing when a new product was coming, what the steps were and what meetings they could attend to bring the HF agenda forward. The following quote and researcher notes from early 2010 exemplify these points:

HFS: 'how do I find out when things (design activities) are happening? – there must be a schedule – I'd like to put this on my calendar – a whole lot of work would come.'

Researcher notes: 'HFS is not sure how to get in.'

The main reflection documented from this stage was that HF needed repositioning in the organisation. Senior management and engineering lacked knowledge of the HFS and what value they could provide to the assembly design process. The HFSs were rarely on the shop floor, and did not otherwise have much contact with engineers. HFS performed a narrow range of reactive assessments, and their reports and recommendations were not provided to engineering to inform future assembly builds. It was evident that HFS needed to become better informed about the design process and the business processes used in the organisation. To help improve the positioning and networking of HF in the organisation, we recommended the need for a steering committee with Senior Directors from various departments. A steering committee would also help ensure stability of the collaboration during organisational changes and management departures.

3.3 Phase 2: seeking the HF fit

In the second phase of the collaboration, called 'seeking the HF fit', the plan was to engage more senior management in HF integration, get access to relevant design initiatives to integrate HF and learn about the company's strategic goals and how HF could help. Through increased involvement of the Senior Director of Engineering, a steering committee was formed with seven senior managers and directors. Organisational changes within the company were occurring at the same time as the steering committee was formed, which resulted in challenges scheduling meetings, planning and committing to initiatives in the collaboration.

We noted that a new Senior Director had been appointed who was bringing a background in the Toyota management system and continuous improvement and we observed visible postings on the shop floor of hoshins, kaizens and gemba walks related to this new direction. The senior management group were entering a phase of new strategic planning for the organisation with a focus on 'new product realization'.

While organisational change hindered meetings and commitment to initiatives, it also offered an opportunity to the HFS team to improve their understanding of the strategic goals of the organisation and how HF may align with them. We conducted a cognitive mapping exercise and workshop with the steering committee to understand their perceptions of the link between HF and the organisations' strategic goals (for details, see Village et al. 2012b; Village, Salustri, and Neumann, forthcoming). The workshop revealed that musculoskeletal injuries (an OH&S perspective) were rarely discussed. Instead, directors were concerned about reducing worker fatigue, which they saw as an outcome of poor

assembly systems design. They believed if workers were less fatigued, then their ability to notice defects would improve and this would enhance product quality. This information would be critical for helping the HFS team realise how best to 'position' or frame HF within the engineering process.

In the 'seeking the HF fit' phase, a number of initiatives began, including having HFS participate in failure mode effects analysis (FMEA) meetings to understand the connections with HF (an initiative discussed during the process mapping in the first phase). Another initiative involved HF assessment of a newly proposed 'lean' pallet line from CAD drawings, and later in early mock-ups of workstations. One student developed a discrete event simulation of the assembly steps to assist with predictions of bottlenecks and worker fatigue. Another student was developing a digital tool to evaluate workstation layout. These initiatives proceeded, although few engineers from the organisation were involved at this point. Despite assistance from the Senior Engineering Director, the HFS team felt that they were trying to 'push' initiatives into engineering, but getting little traction in the way of participation or interest.

As part of 'seeking the HF fit', we conducted an evaluation and needs assessment of previous HF training provided to engineers from outside consultants. Through a survey and focus group, HFS learned that engineers rarely used the generic HF education, and information provided in the training about risk factors and injuries were not considered useful to their design tasks. Engineers reported that due to tight time constraints, 80–90% of their design elements are reused from past work. HFS learned that a better 'fit' for HF information would be the creation of 'benchmark' or 'best in class' HF designs (e.g. of tools or fixtures) in the form of easily applied drawings or rules. This information on 'fit' would also prove valuable for planning actions in the next phase.

Unfortunately, another organisational change resulted in the Senior Engineering Director leaving the organisation and no immediate replacement in the collaboration. In the fall of 2011, reflective interviews were conducted with each member of the steering committee to ascertain what was working and what else could help with the goals of the collaboration. A main finding was that HF lacked visibility. One member stated that HFS needs to:

show that you want to get in there and roll up your sleeves.

Another stated:

when you have something to change or want to drive ergo improvement – do a demonstration and show what physically changes.

It was emphasised that HF needs to be tangible and engineering-like to be accepted. One initiative was considered successful because:

it is very concrete and practical – a traditional engineering view.

Managers said HF has to look like engineering initiatives with a project charter that includes timelines, deliverables, return on investment and a sponsor. This would require a dramatic change in how the HFS plan and carry out their activities in order to 'fit' with the engineers' work style.

Reflections on the HF challenges and successes during this phase reinforced that HF needs to be aligned with the organisations' strategic goals, especially the goal of improving assembly quality. One manager stated that 'we need HF incorporated with our deliverables'. The language and metrics of quality were foreign to HFS, therefore efforts increased to interview those responsible for measuring and improving quality, to review and understand the quality data within the organisation and the scientific literature and to attempt to find the 'fit' between quality data and HF concerns.

Our reflections at this stage also reinforced that HFS need to learn more about engineering processes, their language, tools and their goals. We further reflected on the concept of HF as continuous improvement, rather than problem identification and control and realised we needed tools to quantify and demonstrate HF as continuous improvement. We realised that the integration of HF into design processes within the organisation, at that point in time, might collapse without visible demonstration of its value to engineering or senior management.

3.4 Phase 3: HFS acclimate and strategically align with engineering

In the third phase, the plan was to make HF more engineering-like and visible on the shop floor by drafting engineering charters for HF activities, demonstrating HF initiatives and showing HF as a means to improve quality and reduce operator fatigue. We looked for ways to engage more engineers, and to develop useful tools and metrics that would include HF. With the departure of the Senior Director, a new Senior Director and project leader were appointed to the collaboration. Another large organisational change and extensive downsizing forced a more streamlined alignment of personnel and a tighter focus on strategic goals in the organisation. It was emphasised that HF initiatives would only survive if they could help deliver on the business goals.

As planned, the HFSs increased their activity and visibility on the manufacturing floor, participating in the new, continuous improvement initiatives such as kaizens and gemba walks, and discussing the connection between worker

postures and assembly forces to worker fatigue and therefore assembly quality. Under a new engineering charter, HFS participated in FMEA meetings, using a newly devised HF-FMEA score to indicate risks of injury to a worker (Village et al. 2011). During meetings, the HFS helped engineers see that defects occurring in assembly were at times due to challenges in seeing, detecting or sensing from tactile feedback, a good quality assembly task. Solutions to improve HF were discussed during these meetings, prior to any parts or equipment yet being manufactured. HF input and changes were being demonstrated to an increasing number of engineers.

The HFS team also worked together with product-focused engineers to prioritise tasks for improvement that had both engineering concerns (e.g. slow assembly times) and HF concerns for operators (e.g. difficult assembly motions). Realising that traditional HF tools are ill-suited to communicating assembly difficulties, rather than injury risk, the HFS team adapted engineering design tools (e.g. design-for-assembly) and used these to score and compare assembly tasks and monitor their improvement (see Village 2014; Village et al. 2012a for more information). Reflections from the previous phase about making HF visible led to demonstrations in this phase to show how HF-adapted tools can improve assembly steps. The demonstrations resulted in the Senior Director of Engineering becoming directly involved in HF for the first time. The Director said 'if you have something that can help us improve assembly quality, we can implement it fast'. Workshops with engineers were conducted to test and refine the tools, and within four months, HF would be incorporated into a controlled engineering document with required HF targets enforced by senior management.

This phase represented a 'tipping point' for integration of HF into design processes. The HFS physically moved to the engineering department which provided improved access to people, meetings, documents, software, schedules and to the shop floor where new products and processes were being tested. Physical proximity, combined with a focus on helping engineers meet their goals, resulted in HF being positioned as a means to help improve assembly quality. This strategic alignment led to increasing requests for HF assistance from engineers. Instead of attempting to 'push' their way into engineering, acclimation and strategic alignment led to a 'pull' for HF from engineers and management. With subsequent products, the HFS was given key sign-off status at various stages of assembly design process. Appropriate HF tools led to adoption of HF in the design process and ensured sustainability of HF for subsequent builds regardless of changes in HFS or engineering personnel. By becoming a resource to help improve the goals of engineers, HF became a sustainable part of the design process.

3.5 HF changes resulting from the action research collaboration

Although our AR study did not set out to 'measure' changes or outcomes in a pre-post fashion, we suggest that there are signs that indicate improved integration of HF into production design processes in the organisation – our collaboration goal. There were also signs that both HFS and engineers had changed their work practices to include proactive HF, and that their knowledge of HF integration in design had increased. With no HF considerations in any design stages initially and most HF assessments being reactive (after an injury or incident), by the third phase of the collaboration there were HF targets incorporated into tools at several design stages. Senior Directors were holding their engineers responsible for meeting the HF targets in the design process, and the HFS had key sign-off. As shown in Figure 2, the self-reported percentage of time the HFS performed proactive HF work has increased from 3.5% in 2010 to 72% in 2013. The number of engineers the HFS worked directly with increased from 15 in the first phase to 70 in the third phase. This illustrates that HFS acquired new knowledge of the engineering design process, learned to identify appropriate engineers to work with, adapted engineering design tools to include HF and acquired new work practices of HF sign-off during the collaboration. From documentation and observation of subsequent assembly design cycles, the HFS participated with engineers in all assessments and solution development for the new product lines. Changes were documented to parts, processes, materials and fixtures arising from the inclusion of HF in these early design stages. When the HFS was asked at phase three to reflect on the collaboration and

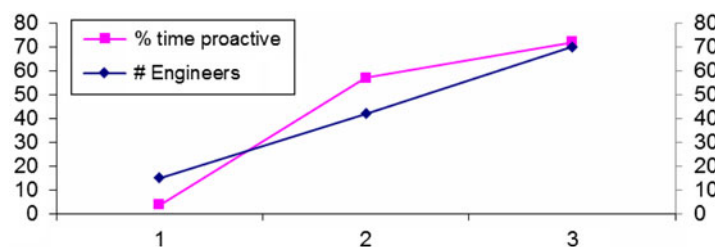


Figure 2. The number of engineers participating in HF, and the percentage of time the HFS spent in proactive HF work in each of three phases of the collaboration.

what has helped with HF integration, the response was ‘being involved in meetings where you can have a say and be part of a process’. When asked what has gotten you involved in meetings, the HFS stated:

Certainly having the (collaboration) project – and (the project manager), someone consistent – getting involved in the engineering group to do a needs analysis and learning from those meetings – learning the engineering process, their tools and techniques. As the project has gone on, I’m always thinking now how to integrate – it’s always in my head.

Results of the collaboration effort were presented to engineers and Senior Directors for verification and confirmation. We asked after the presentation: ‘to what extent has this collaboration changed the way you, as engineers, think about HF?’

One engineering manager said, referring to working with an internal HFS:

I used to come to you (for occasional HF advice), but now we both get called when something happens – it’s like: welcome to the party.

This change in attitude and openness from engineers to HF inclusion is very different from the 2010 quote from the HFS who did not know how to get ‘in’ to the design process. The framework-inspired macro-ergonomic approach led the industry-research team to undertake numerous initiatives over the three years of collaboration. Not all were successful, but as one Senior Director who had participated in the collaboration from the beginning stated:

the way product and fixture designs are going are definitely in the right direction – from when I joined (the collaboration) to where we’re at is night and day and you can say the same thing with the assembly line – we’ve certainly made it easier on the operator in what they’re doing – not every single initiative we worked on was successful but that’s the nature of the beast – you can’t expect that – some things are going to stick and some things won’t but you’ve got to keep trying – even the ones that didn’t stick, or failed, gave you the opportunity to learn things and get to know people and show them what you have.

4. Discussion

The first purpose of this paper was to demonstrate one way to conduct and communicate AR in a macro-ergonomics intervention. The first part of the paper has highlighted unique features of an AR approach and how it worked in the collaboration, including the evolving role of the researcher as participant ‘in’ the research, the concurrent collection and analysis of data to inform next steps, the ongoing use of literature and theory to inform action and the importance of continual reflection on actions for planning the next actions (Levin 2012; Neumann, Dixon, and Ekman 2012; Ottosson 2003). This paper has also demonstrated that reporting of AR findings tends to be unconventional compared with other scientific studies because the methods and results are difficult to disentangle (Davis 2007; Fisher and Phelps 2006).

The second section then provided details of the AR collaboration, using the model of the AR spiral with three non-linear cycles of plan, act, observe and reflect (Meyer 2000). This helped illustrate how actions taken were informed by the observations and reflections, which influenced subsequent actions. Actions to integrate HF were not planned in advance, but were ongoing and embedded in the research process. As Commissaris et al. (2006) and others discuss, this is in contrast to most participatory ergonomics interventions, or change-management approaches, where a discrete intervention is ‘planned’ and then ‘tested’ (van Eerd et al. 2010). AR has been called ‘emergent’ change, as opposed to ‘planned’ change since the process of change unfolds through the interplay of multiple variables in the organisation (Bamford and Forrester 2003). In this way, AR is more closely aligned with soft systems methodologies (Checkland 1985), and organisational learning (Commissaris et al. 2006; Docherty, Forslin, and Shani 2002) where there is more emphasis on learning from the process and less on the outcome evaluation.

The second goal of this paper was to demonstrate how AR can lead to a deep understanding of ‘how’ to integrate HF into production systems design. It is about meaning of action rather than testing a predetermined hypothesis (Carter 2007). We started with only a broad framework suggesting that we needed to create opportunities to integrate HF proactively into as many levels of the design process as possible (Neumann and Village 2012). The constant reflecting and questioning within the AR approach helped the team learn from their many initiatives what was working and not working, and to adapt accordingly. Others have also reported on this strength of AR and longitudinal case studies for inferring causal relationships based on long-term observations of multiple actions, providing a broad holistic picture (Bamford and Forrester 2003).

At the end of the first phase, we recommended a steering committee to improve the positioning, networking and stability of the HF work in the collaboration. Organisational strategies were shifting and it was apparent that HFSs were removed from main-line strategic and business goals, much like a ‘side-car’ status (Neumann, Ekman, and Winkel 2009; Dixon, Therberge, and Cole 2009). Other researchers have noted that if HF is positioned in line with company goals, it is more likely to be effective (Berlin 2011; Drury 2000; Dul and Neumann 2009; Eklund 1997). We capitalised on the strategic changes in the organisation to link perceptions of HF to the new strategic goals.

By constantly questioning our assumptions, carefully listening to recordings from meetings, reflecting with the research team and consulting literature and theory, we began to discover ‘how’ HF needed to be framed to ‘fit’ within the engineering

team in this organisation. We learned from the cognitive mapping exercise with senior management that their goal of good production systems design is to minimise operator fatigue (not injuries) to improve performance, and therefore their main business goal of good quality assembly. This understanding stretched the HFS to think and act outside of their comfort zone. As others have found, the HFS needed to learn the engineering language, design processes, tools and metrics in order to become more 'engineering-like' and visible (Broberg 2007; Falck and Rosenqvist 2012; Strasser and Zink 2007; Waterson and Kolose 2010; Wells et al. 2007; Wulff, Westgaard, and Rasmussen 1999). The acclimation and strategic alignment of HF with engineering coincided with a tipping point in the collaboration. The perception and interest of engineers in HF changed when it became a means to help improve their goals and business performance. Patton (2011) suggests that when researchers infuse team discussions with questions and data, this facilitates systematic reflection that results in effective process sustainability.

The third goal of the paper was to demonstrate the benefits to researchers and practitioners of adopting a reflective stance in their HF work. Reflection occurs when practitioners think about what they are doing and question the framing of the problem they are trying to solve, their tacit understandings of practice, their strategies and theories implicit in behaviour and their feelings for a situation that has led to action (Schön 1991). A practitioner can become a 'reflective researcher' and improve their ability to deal with situations of uncertainty, instability, uniqueness and value conflict (Schön 1991). The result of reflective practice is that the practitioner may criticise his/her initial understanding of a phenomenon, construct a new one and test it, and set a new frame or role for himself or herself. In this study, reflection allowed us to realise that the lack of HF in engineering design in this organisation was not because engineers lacked interest in designing for humans, but rather that relevant HF information had not been provided to engineers in a way they could readily use it in their design process. By gaining an inside view of the experience of practice, and re-framing the problem, we were able to gain insights from the implementation as we were participating in it.

At an individual level, active reflection and developing reflective conversation can improve understanding of issues, open greater possibilities and improve personal performance or mastery (Ellegard et al. 1992; Senge 2006). Broberg and Hermund (2004) describe ergonomists as 'political reflective navigators' who work politically towards an HF agenda attempting to gain social support, and reflectively by changing to different rolls in different contexts mobilising different kinds of knowledge and tools as they navigate complex change processes. Hignett and Wilson (2004) suggest that since HF is socially situated, practitioners need a paradigm shift from solely quantitative to more qualitative methods through improved education and reflective practice.

At a group or organisational level, the reflexive loops, iterative action for change and shared observations with users can lead to a new collective practice, which Docherty, Forslin, and Shani (2002) suggest is organisational learning. Instead of expert-driven or expert-facilitated interventions, Docherty, Forslin, and Shani (2002) refer to organisational learning as the 'third paradigm' of interventions where reflexivity or thoughtfulness is systematically performed to integrate system perspectives and subjects' perspectives with continuous questioning of group tasks, operative rules, etc. Gustavsen (2003) suggests that two forms of knowledge diffusion are operating in parallel in AR. Knowledge is transferred to the research community and to the participants in the organisation. Balcazar et al. (2004) suggest that when researchers and practitioners work together they are both outside their initial frames of reference, but communicate at a level where old frames can be changed and new ones generated – called 'cogenerative learning'. We encourage researchers and practitioners to use reflexivity when working with organisations to improve their HF efforts, and learning for both parties.

4.1 Methodological challenges in conducting ergonomics action research

While effective in making sustainable changes, there are challenges in conducting AR. Ottosson (2003) suggests that AR is more demanding and complex than classical research in terms of time, resources and skills and experience of the researcher. There is continual balancing regarding roles and actions (Rosecrance and Cook 2000), especially whether the researcher should navigate and direct the action, or facilitate and coach those in the organisation to take the action. While situated learning, and reflection with researchers has been suggested (Seim, Broberg, and Anderson 2012), more research is needed regarding which roles work best for researchers in different contexts. Ultimately, the organisation must 'own' the actions in ways that work for them. The continual reflection and ongoing analysis of the actions requires the researcher to be a 'participant-observer' always questioning what the researchers or practitioners could do better. Levin (2012) suggests that creating the necessary distance between the involvement in the change process and the accompanying reflexive process that aims at explaining the phenomenon is the essence of building integrity in AR.

From the organisation's point of view, AR may also be considered time-consuming and resource-intensive. Since HF integration was not a goal shared by everyone in the organisation, there was considerable navigation needed by the HFS team to pay attention to the interests of different engineering groups and persuade others of our intended goal. The HFS, and later the engineer who became our project manager, dedicated time with researchers, especially to help prepare for meetings

or other events and afterwards to help interpret and make sense of organisational events or actions. Because researchers acted with HFS in meetings and other activities, at times there were problems with role clarity, and misunderstandings regarding responsibility for tasks.

Another methodological challenge is that findings are based on a single case study, not randomly selected. However, Patton (2011) suggests that purposeful and intentional sampling is a strength because it provides important information about field-based processes in an information-rich case that would otherwise be unavailable. The case study method is a preferred approach when 'how' and 'why' questions are posed, when the investigator has little control over events and when the focus is on studying phenomenon within a real life context (Yin 1994). The exploratory nature of the case study allows flexibility and lends itself to qualitative data collection and analysis to understand why people make choices or carry out tasks in a particular way (Hignett and Wilson 2004).

Although the series of events leading to organisational change and learning in our collaboration would naturally unfold differently in other organisations and with different people involved, the lessons learned may be valuable for others attempting to conduct ergonomics AR studies, or to integrate HF in their design processes.

Instead of generalisability, in qualitative studies where each case is unique to a context (i.e. when, where and who), the concept of transferability is more relevant. Moray (1994, 1995) has stated that the value of qualitative studies in ergonomics is to generalise findings from 'situations' to other and different systems, rather than generalising based on statistical analysis. Instead of repeatability, the careful documentation of the data collection and analysis provides a credible link between the data and the results. Qualitative studies are considered dependable (rather than repeatable) when there is a consistency in patterns of thought and behaviour of subjects. Since we conducted multiple initiatives with different groups of engineers within the large case study organisation, our study design was strengthened with such multiple embedded cases. This allowed us to contrast the strengths and weaknesses of each initiative. It also minimises bias from any single 'success' case. The generalisability of these findings is consistent with contingency theory which suggests that for a proposition to hold, assumptions must be made about the starting premise, boundaries and system states (Donaldson 2001). Contingency theory also suggests that concepts in any theory of organisational change must 'fit' the environment, rather than be generalised or adopted outright (Miller 1978).

During the three years, the collaborating organisation underwent a major shift in organisational strategy, multiple personnel changes, downsizing and layoffs and realignment of various departments. Such organisational changes may make our findings open to criticism. Other intervention studies have been known to suffer, or even collapse with such disturbances (Dixon, Therberge, and Cole 2009; Neumann, Ekman, and Winkel 2009). However, the reflexive nature of the AR approach allowed adaptation and continuation of HF efforts despite the upheaval. In fact, making progress under these difficult circumstances further highlights our success at helping engineers understand how HF can help them achieve their goals. Viewing the organisation with reference to complexity theory reminded us that industries with short product cycles view rapid and relentless continual change as necessary for survival. Likewise, for HF to be implemented in such a volatile environment, we needed to shift from viewing change as a barrier to viewing change as a potential facilitator of HF as it provided new opportunities to work with stakeholders in new ways.

For researchers and practitioners interested in macro-ergonomic AR interventions, we recommend setting up a structure that allows flexibility for goals and plans to change and develop over time. Since HF may not be a priority for all participants, setting common goals for the collaboration is critical to prevent misunderstandings. Preferably a steering group of senior participants representing all affected groups would be involved early, and a working group including both engineers and HF specialists would collaborate on initiatives. An industry project manager who has the collaboration as a top priority facilitates ownership of the project. There should be both the willingness and resources to experiment and conduct trials. The collaboration may require considerable organisational navigation and ongoing recruitment for support. Participants should expect setbacks and have the perseverance to re-engage on new fronts. Failing at some initiatives can be as much of an opportunity for learning as succeeding. To facilitate learning, plan on reflective one-on-one interviews with participants to actively involve them in replanning. Finally, both industry participants and researchers need the resources and ability to respond to tight timelines sometimes needed by the engineering design process.

5. Conclusions

This longitudinal AR collaboration with an electronics manufacturing firm demonstrated how over a three-year period, HFS went from being completely outside the engineering design process doing reactive HF work to being embedded at numerous stages in the engineering design process doing mostly proactive HF work. We conclude that the AR approach, especially the active reflection, combined with targeting multiple initiatives at different stages of the design process helped the organisation find ways to integrate HF into their processes in a sustainable way. This macro-ergonomics change would not be amenable to a planned step-wise intervention approach, as the steps were not apparent beforehand. The close proximity

and involvement of the researcher in the change, the ongoing interaction with stakeholders, the ability to observe and reflect in real time *in vivo* and the concurrent data collection and analysis led to a deep understanding in this organisation about 'how' to integrate HF into design processes. With the researchers both involved in the process and removed to reflect and theorise, they acted as a catalyst to the change. Researchers helped HFS to navigate the people and processes, and demonstrate HF tools. They coached the HFS, helped interpret actions and meanings, and increasingly nurtured the HFS to continue the HF integration independently. The strength and flexibility of the AR approach demonstrated that change occurred despite downsizing and management turnover in the organisation. This paper provides insight to researchers about how to conduct AR studies where the research question is about 'how' something can occur. It also demonstrates the benefits for practitioners of using a reflective stance to question and improve success of HF goals. Finally, this paper has also demonstrated one method for reporting an AR study when methods and results are not linear as in traditional intervention studies.

Acknowledgements

This work has been supported by the Natural Science and Engineering Research Council, the Workplace Safety Insurance Board of Ontario and BlackBerry Ltd. We also appreciate the time and effort from many HFSs and engineers at BlackBerry Ltd. who collaborated on this study.

References

- Balcazar, F. E., R. R. Taylor, G. W. Kielhofner, K. Tamley, T. Benziger, N. Carlin, and S. Johnson. 2004. *Participatory Community Research: Theories and Methods in Action* (AKA Decades of Behavior Volumes). Washington, DC: American Psychology Association.
- Bamford, D. R., and P. L. Forrester. 2003. "Managing Planned and Emergent Change within an Operations Management Environment." *International Journal of Operations & Production Management* 23: 546–564.
- Berlin, C. 2011. "Human Factors Experiences in Context – Comparing Four Industrial Cases Using a Soft Systems Framework." *The Ergonomics Open Journal* 4: 131–144.
- Boothroyd, R. I., S. B. Fawcett, and P. G. Foster-Fishman. 2004. *Participatory Community Research: Theories and Methods in Action* (AKA Decades of Behavior Volumes). Washington, DC: American Psychological Association.
- Broberg, O. 2007. "Integrating Ergonomics into Engineering: Empirical Evidence and Implications for the Ergonomists." *Human Factors and Ergonomics in Manufacturing* 17: 353–366.
- Broberg, O., and I. Hermund. 2004. "The OHS Consultant as a 'Political Reflective Navigator' in Technological Change Processes." *International Journal of Industrial Ergonomics* 33: 315–326.
- Brown, S. L., and K. M. Eisenhardt. 1997. "The Art of Continuous Change: Linking Complexity Theory and Time-Paced Evolution in Relentlessly Shifting Organizations." *Administrative Science Quarterly* 42 (1): 1–34.
- Carter, S. M. 2007, December. "Justifying Knowledge, Justifying Method, Taking Action: Epistemologies, Methodologies, and Methods in Qualitative Research." *Qualitative Health Research* 17: 1316–1328.
- Checkland, P. 1985. "Achieving 'Desirable and Feasible' Change: An Application of Soft Systems Methodology." *Journal of Operational Research Society* 36: 821–831.
- Commissaris, D. A. C. M., N. Schoenmaker, E. A. Th. Beune, and S. M. Eikhout. 2006. "Applying Principles of Change Management in Ergonomic Projects: A Case Study." *Human Factors and Ergonomics in Manufacturing* 16: 195–223.
- Davis, J. M. 2007. "Rethinking the Architecture: An Action Researcher's Resolution to Writing and Presenting Their Thesis." *Action Research* 5: 181–198.
- Dick, B., E. Stringer, and C. Huxham. 2009. "Theory in Action Research." *Action Research* 7: 5–12.
- Dixon, S. M., N. Therberge, and D. C. Cole. 2009. "Sustaining Management Commitment to Workplace Health Programs: The Case of Participatory Ergonomics." *Relations Industrielles/Industrial Relations* 64: 50–64.
- Docherty, P., J. Forslin, and A. B. (Rami) Shani. 2002. *Creating Sustainable Work Systems: Emerging Perspectives and Practices*. London: Routledge.
- Donaldson, L. 2001. *The Contingency Theory of Organizations (Foundation of Organizational Science)*. Thousand Oaks, CA: Sage.
- Drury, C. G. 2000. "Human Factors and Quality: Integration and New Directions." *Human Factors and Ergonomics in Manufacturing* 10: 45–59.
- Dul, J., and P. Neumann. 2009. "Ergonomics Contributions to Company Strategies." *Applied Ergonomics* 40: 745–752.
- Eklund, J. 1997. "Ergonomics, Quality and Continuous Improvement – Conceptual and Empirical Relationships in an Industrial Context." *Ergonomics* 40: 982–1001.
- Ellegard, K., D. Jonsson, T. Engstrom, M. I. Johansson, L. Medo, and B. Johansson. 1992. "Reflective Production in the Final Assembly of Motor Vehicles – An Emerging Swedish Challenge." *International Journal of Operations & Production Management* 12 (7): 117–134.
- Falck, A.-C., and M. Rosenqvist. 2012. "What Are the Obstacles and Needs of Proactive Ergonomics Measures at Early Product Development Stages? – An Interview Study in Five Swedish Companies." *International Journal of Industrial Ergonomics* 42: 406–414.
- Fisher, K., and R. Phelps. 2006. "Recipe or Performing Art?" *Action Research* 4: 143–164.
- Friedman, V. J., and T. Rogers. 2009. "There is Nothing so Theoretical as Good Action Research." *Action Research* 7: 31–47.
- Gustavsen, B. 2003. "Action Research and the Problem of the Single Case." *Concepts and Transformation* 8 (1): 93–99.

- Hignett, S., and J. R. Wilson. 2004. "The Role for Qualitative Methodology in Ergonomics: A Case Study to Explore Theoretical Issues." *Theoretical Issues in Ergonomics Science* 5 (6): 473–493.
- Huxam, C., and S. Vangen. 2003, July. "Researching Organizational Practice through Action Research Case Studies and Design Choices." *Organizational Research Methods* 6 (3): 383–403.
- Lander, E., and J. K. Liker. 2007. "The Toyota Production System and Art: Making Highly Customized and Creative Products the Toyota Way." *International Journal of Production Research* 45: 3681–3698.
- Levin, M. 2012. "Academic Integrity in Action Research." *Action Research* 10: 133–149.
- Lim, A., J. Village, F. Salustri, and W. P. Neumann. 2014. "Process Mapping as a Tool for Participative Integration of Human Factors into Work System Design." *European Journal of Industrial Engineering* 18 (2). doi:10.1504/EJIE.2014.060477.
- Mathews, K. M., M. C. White, and R. G. Long. 1999. "Why Study the Complexity Sciences in the Social Sciences." *Human Relations* 52 (4): 439–461.
- Meyer, J. 2000. "Qualitative Research in Health Care: Using Qualitative Methods in Health Related Action Research." *British Medical Journal* 320: 178–181.
- Miller, J. A. 1978. "Contingency Theory, Values and Change." *Human Relations* 31 (10): 885–904.
- Mingers, J., and L. White. 2010. "A Review of the Recent Contribution of Systems Thinking to Operational and Management Science." *European Journal of Operational Research* 207: 1147–1161.
- Moray, N. 1994. "'De Maximum non Curat Lex' or How Context Reduces Science to Art in the Practice of Human Factors." Proceedings of the 38th Annual Meeting of the Human Factors and Ergonomics Society, Nashville, TN, 526–530.
- Moray, N. 1995. "Ergonomics and the Global Problems of the Twenty-First Century." *Ergonomics* 38 (8): 1691–1707.
- Neumann, W. P., S. Dixon, and M. Ekman. 2012. "Ergonomics Action Research I: Shifting from Hypothesis Testing to Experiential Learning." *Ergonomics* 55 (10): 1127–1139.
- Neumann, W. P., M. Ekman, and J. Winkel. 2009. "Integrating Ergonomics into Production System Development – The Volvo Powertrain Case." *Applied Ergonomics* 40: 527–537.
- Neumann, W. P., and J. Village. 2012. "A Framework Supporting the Process of Integrating Human Factors into Systems Design." *Ergonomics* 55 (10): 1140–1156.
- Nielsen, A., K. Svensson, and L. Svensson. 2006. *Action and Interactive Research Beyond Practice and Theory*. Maastricht: Shaker.
- Ottosson, S. 2003. "Participation Action Research – A Key to Improved Knowledge of Management." *Technovation* 23: 87–94.
- Palmer, I., and R. Dunford. 2008. "Organizational Change and the Importance of Embedded Assumptions." *British Journal of Management* 19: 520–532.
- Patton, M. Q. 2011. *Developmental Evaluation: Applying Complexity Concepts to Enhance Innovation and Use*. New York: Guildford Press.
- Poonamallee, L. 2009. "Building Grounded Theory in Action Research through the Interplay of Subjective Ontology and Objective Epistemology." *Action Research* 7: 69–83.
- Raymer, A. 2009. "Big Returns for a Little More Investment." *Action Research* 9: 1.
- Rosecrance, J. C., and T. M. Cook. 2000. "The Use of Participatory Action Research and Ergonomics in the Prevention of Work-Related Musculoskeletal Disorders in the Newspaper Industry." *Applied Occupational and Environmental Hygiene* 15 (3): 255–262.
- Schön, D. A. 1991. *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books.
- Seim, R., O. Broberg, and V. Anderson. 2012. "Ergonomics in Design Processes: The Journey from Ergonomist toward Workspace Designer." *Human Factors and Ergonomics in Manufacturing & Service Industries, Early View* (published online June 25, 2012), 1–15.
- Senge, P. M. 2006. *The Fifth Discipline: The Art & Practice of the Learning Organization*. 2nd ed. New York, NY: Doubleday Currency.
- Strasser, H., and K. Zink. 2007. "Modular Course Provision for Professional Ergonomists with Micro- and Macro-Ergonomic Design Competency in the System 'Human Being-Technology-Organization'." *Theoretical Issues in Ergonomics Science* 8: 349–363.
- Strauss, A., and J. Corbin. 1990. *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Newbury Park, CA: Sage.
- Suarez-Balcazar, Y., M. I. Davis, J. Ferrari, P. Nyden, B. Olson, J. Alvarez, P. Molloy, and P. Toro. 2004. *University-Community Partnerships: A Framework and an Exemplar* (AKA Decades of Behavior Volumes). Washington, DC: American Psychological Association.
- van Eerd, D., D. Cole, E. Irvin, Q. Mahood, K. Keown, N. Theberge, J. Village, M. St. Vincent, and K. Cullen. 2010. "Process and Implementation of Participatory Ergonomic Interventions: A Systematic Review." *Ergonomics* 53: 1153–1166.
- Village, J. 2014. "Integrating Human Factors into a Company's Production Design Processes." PhD diss., Department of Mechanical and Industrial Engineering, Ryerson University, Toronto, Canada.
- Village, J., T. Annett, M. Greig, and W. P. Neumann. 2012a. "Participatory Development of Ergonomic Design-for-Fixture Guidelines: A Case Study." Association of Canadian Ergonomists Annual Conference, Halifax, NS.
- Village, J., T. Annett, E. Lin, M. Greig, and W. P. Neumann. 2011. "Adapting the Failure Modes Effect Analysis (FMEA) for Early Detection of Human Factors Concerns." Proceedings of the 42nd Annual Conference of Association of Canadian Ergonomists, London, Ontario.
- Village, J., M. Greig, F. A. Salustri, and W. P. Neumann. 2012b. "Linking Human Factors to Corporate Strategy with Cognitive Mapping Techniques." *Work* 41: 2776–2780.
- Village, J., F. Salustri, and W. P. Neumann. Forthcoming. "Cognitive Mapping Links Human Factors to Corporate Strategies." *European Journal of Industrial Engineering*.
- Waterson, P., and S. L. Kolose. 2010. "Exploring the Social and Organizational Aspects of Human Factors Integration: A Framework and a Case Study." *Safety Science* 48: 482–490.
- Wells, R., S. E. Mathiassen, L. Medbo, and J. Winkel. 2007. "Time – A Key Issue for Musculoskeletal Health and Manufacturing." *Applied Ergonomics* 38: 733–744.

- Whitehead, J. 2009. "Generating Living Theory and Understanding in Action Research Studies." *Action Research* 7: 85–99.
- Wulff, I. A., R. H. Westgaard, and B. Rasmussen. 1999. "Ergonomic Criteria in Large-Scale Engineering Design-II: Evaluating and Applying Requirements in the Real World of Design." *Applied Ergonomics* 30: 207–221.
- Yin, R. K. 1994. *Case Study Research: Design and Methods*. 2nd ed. Thousand Oaks, CA: Sage.
- Zink, K. J., U. Steimle, and D. Schroder. 2008. "Comprehensive Change Management Concepts: Development of a Participatory Approach." *Applied Ergonomics* 39 (4): 527–538.