Trial-and-Error based Innovation: Physical Iteration Games as Collaborative Strategy in Product Design

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ABSTRACT

Phenomenology opens for seeing mind and body as inseparable in design action. Scandinavian researchers have shown that such an anti-dualistic approach to design is facilitated by employment of physicality as a communication tool. This participatory action research project is arranged to explore the potentials of using Rapid Prototyping (RP)-produced physicality as a tool for the facilitation of creative collaboration between dissimilar stakeholders of design teams. It is found that product design procedures can be supported by RP technology in iterative patterns, which seem to catalyse 'mind/body experiences' and understanding of individual and integrated contributions to the totality. Such 'physical iteration games' are integrated in the 'language games' we play in design, in procedures where 'sense-based' and 'word-based' languages of the actors seem to merge. Two concrete design research projects will be described and the findings elaborated.

Keywords Collaborative design, Rapid Prototyping, Iteration

Rapid Prototyping (RP) technology, also called Layer Manufacturing, is based upon fast, cheap and accurate materialisation of (virtual) 3D CAD models in different materials and techniques [9]. The technology has in a few years revolutionized the phase of product design procedures where a finished concept is to be modelled and evaluated – traditionally called *prototyping* [14]. This

project focuses on earlier and later design phases.

Approaching real life complexity

Cross et al. [5] describe how early design process models were based in engineering design of deterministic and mechanistic structures: prescriptive, rational, linear, algorithmic, theoretical and problem focused. These were criticised by design methodologists in the early nineteen seventies, who suggested radically changed models of practical structures: descriptive, intuitive, cyclic, heuristic, empirical and solution focused – based upon tacit knowledge and 'primary generators' [6]. After 30 years of opposed approaches, a distinct tendency today is to see product design processes in contexts of real life complexity where not only the integrated efforts of engineers and industrial designers are called for, but where several actors of diverse disciplinary background together with future users must learn how to collaborate [16]. Traditional design methodology approaches complexity through *reduction,* which may function well in contexts of redesign of well known premises, but for the purpose of eliciting collaborative and creative efforts between dissimilar actors with different values, norms, cultural backgrounds and preferences, recent design research trends indicate a need for new ways of understanding such realities [21].

Since Enlightenment, science has regarded the human mind as 'subjective'- incapable of 'objectivity'- and therefore untrustworthy. But since personal engagement, abilities and emotions are preconditions for creativity [17, 11], the elimination of the subjective realm in research on design action does not give meaning. The challenge then becomes to approach design from a position of mind *and* body interaction. But we seem to lack basic understanding of creative action with subjective involvement in integrated wholes, and if one subject shall be understood in his/her mind/body totality – how shall several subjects

trying to coordinate dissimilar subjective values (and rational knowledge) in shared objective action be approached? For the assessment of these difficult questions I have chosen to depart from the action itself – and from a phenomenological perspective.

Husserl rejects the Cartesian dualistic separation between the objective world as it is in itself and the subjective world as it appears to the individual. The objective world to him is the outer stage for human 'intentional acts', which are essential elements of our 'lifeworlds'. Direct and immediate experience of phenomena in the world presupposes such intentional acts where sense perceptions like seeing, touching and smelling serve as formative elements [12]. A phenomenological approach to research thereby becomes not only to describe a matter as it appears as experienced object, but also to describe the experience of the object. Such a humanly experienced lifeworld is neither purely objective nor purely subjective [22].

I will call an experience perceived through the human senses according to this line of thought a 'mind/body experience'. Phenomenology has inspired a number of Scandinavian researchers to approach collaborative design through the employment of *tools* with preconditions for elicitation of shared mind/body experiences. I have selected three representatives: Ehn, Brandt and Lerdahl.

Research on communication tools

Ehn [8] draws inspiration from Husserl's successor Heidegger and focuses his distinction between two important positions for understanding practical artefacts; they can be either 'ready-to-hand' (*zuhanden* - a hammer is not an extended object to an acting carpenter) or they can be 'present-at-hand' (*vorhanden* - a hammer can be reflected upon also by a carpenter). Thereby use and understanding become different aspects of the same activity. But for theoretical reflection on design, ready-to-hand action must be made present-at-hand through 'breakdowns'. Thereby for instance users and designers can communicate on a background of understanding through creation of 'language games' described by Wittgenstein [19] where some shared language becomes the means for communication. For the facilitation of such games, Ehn suggests several approaches to 'design-by-doing' where different kinds of socially constructed artefacts serve as tools to facilitate the breakdown of ready-to-hand experiences – "because of the interaction and reflection they support" [8]. Such mock-ups express propositional knowledge and practical understanding through 'hands-on-experience'. They can be made from

cardboard or simple available physical objects for 'ready-to-hand' use.

Brandt [1] elaborates further on these basic principles and stages 'event-driven product development' procedures where materialised representations of different kinds play a central role as communication tools and facilitate the communication between developers and users towards shared learning and understanding. Brandt and Grunnet [2] demonstrate how 'bodily approach' can be brought into user design procedures through the application of drama and props1 in the development of advanced electronic service tools. They focus props not only as 'things to think with' but also as 'things to act with' to gain shared real life understanding of all aspects of the emerging product concepts.

Similarly Lerdahl [11] approaches collaboration in design teams, but focuses procedures and models for elicitation of creativity in early project phases - where physicality and object relations play important roles in staging mind/body engagement of the participants. For instance in scenario plays aimed at creation of visions, employment of playgrounds and activity zones equipped with diverse physical artefacts for engagement and fun-making are central issues. He argues that creative collaboration preferably should take place on abstracted levels of interaction – and eventually proceed to material levels through alternations between abstractions and details.

These contributions have undoubtedly brought valuable insight into understanding of basic collaborative structures in design, where real life mind/body experiences are of central importance. But in product design, where the integration of frequently conflicting claims of diverse nature is of prime concern, it seems that their approaches could be extended into a landscape of higher *specificity* - and that innovative opportunities to a large extent also may emerge in later and more concrete stages of conceptualisation. Their chosen tools demonstrate convincing collaborative effects, but I find reason to ask whether the demonstrated tools alone are the most appropriate for bringing multiple desires all the way to negotiated solutions – of serving the giving-and-taking of opportunities, of playful experimentation with emerging possibilities, of trying and failing and trying again – not only in imagination, but through hands-on-experienced reality. I ask: To what extent may the RP tool possess inherent possibilities which can serve such aspirations – and thereby contribute to bringing collaborative design one step further towards realisation of *negotiated meaning* in design teams involving many dissimilar stakeholders?

Research on trial-and-error

This research project has been structured to assess these questions. Section A was organised as a case study project including Selective Laser Sintering (SLS) production of 339 rapid prototyped parts for 16 projects (mainly in polyamide) for four sponsoring manufacturing companies and five collaborative student projects, plus Rapid Tools (RT) for three companies. The parts were mainly used for testing of new product concepts and evaluation of technical, functional and aesthetical parameters. In a qualitative research process involving collaborative action, theoretical studies and reflections in the form of discussions and in-depth interviews, the collaborative potentials of the technology slowly emerged over a period of one year. We found that in conceptualisation, strength and accuracy of the produced parts is of moderate importance whereas high speed and low cost are highly important, and accordingly bought a very fast and cheap Concept Modeller from Z-Corp based on plaster and glue and primarily used this in section B. The researcher here followed a Participatory Action Research (PAR) regime where s/he submerges in the material as an active participant [15, 3]. Such research cannot produce value free findings, but local stories with potential for inter-subjective agreements. Two PAR projects with student participation in co-operation with two sponsoring manufacturing companies were now arranged to test and further evaluate the findings of section A: 1) a children's sledge concept based upon a balance principle (for Hamax A.S.) and 2) creative solutions to mouth hygiene (for Jordan A.S.). Video recordings were made of the collaborative meetings, 'soft quantification' schemes of chosen variables were completed to track down the advances, questionnaires were completed, and a process-oriented discussion was video taped. Relevant model material was photographed for documentation.

The balance sledge concept resulted from a two-stage student project. Hamax A.S. wanted to pursue the concept in an RP-supported project with the winning student as a designer in collaboration between four co-actors representing administration, market, engineering and design knowledge. First a steel mock-up was built and tested. Next a new concept was negotiated on a sketch level, designed as a 3D model, materialised as a concept model and negotiated. This procedure was repeated in four iterations with a new meeting for each iteration.

Figure 1 shows the four iterations where parameters like material strength, stiffness, bearing stresses, moulding properties, crash properties, curving functionality, turning properties, assembly properties, turning handle locking

device, steel edge assembly, ergonomics, market image, aesthetics, production/ handling logistics, economics and sales policy were continuously being negotiated in each meeting. When changes in the models were agreed upon, they were simply added to the physical models with clay – and the result thereby represented the outline for the following iteration.

The mouth hygiene project resulted in five different designs of which Jordan A.S. decided to continue the development of three. The first phase was arranged as a

Fig.1
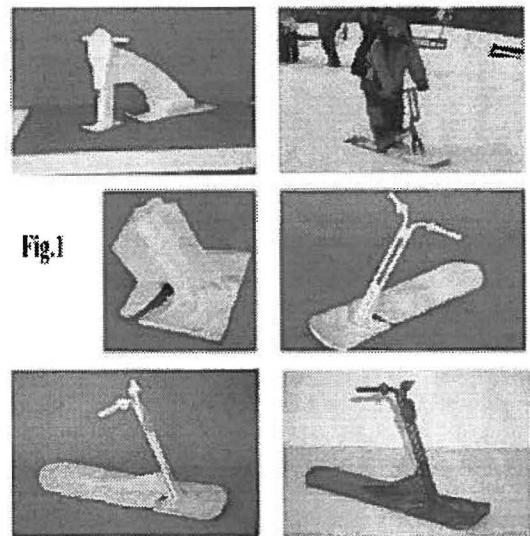
creativity course led by Erik Lerdahl, in accordance with [11]. Initial ideas were elaborated through RP supported concept modelling in four to seven consecutive iterations. For each iteration presentations and discussions were conducted in plenum sessions with representatives for market, engineering and professional design knowledge present. Only one design will be described here, the children's 'motivation brush', which was a collaborative project between four design students, a toothbrush designer, a company engineer and the researcher. The concept was based upon the idea that children can be motivated for tooth brushing through integration of certain graphic sign features in the handle. Three functional concepts were designed, 3D modelled, tested physically as concept models – and two were rejected. After seven physical iterations of the chosen concept including evaluations and discussions, two remained. Each iteration included a large number of drawings and adding clay to iteratively produced RP concept models or existing brushes, as form variations on each basic idea. Each alternative was negotiated between the design actors and tested in the hand. Inter-subjective agreements upon form and function always formed a basis for the next attempt – which was then re-modelled and rapid prototyped anew. Concept models were eventually tested

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by children in realistic settings. Figure 2 shows some of the iterations and clay-modifications included in these procedures.

Fig. 2
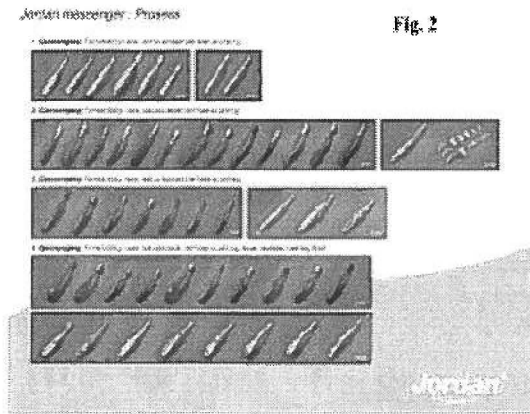
Based upon the experiences acquired through participation in all these projects, the analysis of seven in-depth interviews, nine questionnaires, video recordings of four collaborative meetings and one reflective discussion, a list of nineteen sentences extracting the most important shared experiences and observations has been summarised

by the researcher. According to the principles of PAR, these suggestions have been elaborated in plenum debates and discussions between the students, the manufacturers' representatives and the researcher – and frequently changed until inter-subjective agreements were finally reached.

Negotiated observations from the RP-supported concept development projects:

1. Experienced physicality in the form of models has facilitated the communication between the collaborating design actors - as a 'language without words' which has been understood by all participants regardless of background. 2. Physicality, which could be observed and touched, has given valuable background for establishment of basic understanding of the design problems for everyone involved. 3. Such basic understanding is behind the verbal discussions we have participated in during the project. 4. Through shared seeing and touching of physical models, and after that sharing our sensations through spoken language, we gradually develop shared understanding of the design problems. 5. Such shared understanding of the whole objective of the design problem is a condition for a meaningful contribution from the individual stakeholders who individually may see different aspects of the *problematique* as central issues. 6. According to the above observations, physicality can

be depicted as a 'catalyser' for communication between dissimilar stakeholders of a design team. 7. Physicality can be produced in many ways (e.g. as mock-ups from cardboard, foam or clay), but as a design concept materialises in a project, RP-produced physicality has proven to be a very efficient design tool for elicitation of catalysation effects between collaborating design actors. 8. The tool's ability to produce fast, cheap and exact physical models from virtual 3D models makes it ideal for experimentation with different possible (or impossible) design solutions – including many variants of each idea. 9. Such possibilities open for simultaneous experimentation with many different aspects of design problems such as for instance strength, producibility, material properties, technical functionality, assembly, packaging, ergonomics, aesthetics, market image – in other words parameters of both rational and value-laden nature. 10. If dissimilar stakeholders shall experiment with different specialities in a design project, then it has been found to be convenient to arrange such experiments as iterations. 11. In each such iteration all collaborating stakeholders *must* negotiate their own particular speciality – and simultaneously see their own contribution as part of the experienced totality. 12. The results of negotiated decisions can be seen, touched and experimented with by all actors in each iteration – thereby producing shared meaning and impulses for improvements. 13. An iterative development pattern also opens for experimentation with radical solutions. 14. If the focus of a collaborating team is creativity and search for earlier unknown solutions, iteration procedures can easily be directed towards such objectives by being organised as playgrounds for creative experiments with all actors involved. 15. Many such experiments will naturally lead to experienced breakdowns – and some may produce original results. 16. The completed cases have revealed that RP-produced physicality involves great 'sense feedback' properties, but it is by no means always the best possible design tool because it can not give immediate fingertip/view feedback to the designer like clay can, for instance. 17. The modelling of virtual 3D models on a computer screen produces an alienation effect between the designer and the material, which is compensated by the resulting physicality, but this was still considered as a process obstacle because of the undesirable waiting time. 18. Experiences and reflections in the projects indicate that if material is removed from the concept models through grinding or added manually through use of clay, these drawbacks can be compensated, and 'immediate sense feedback' can be approached. 19. This observation left us to conclude that there is need for appropriate technology for quick and easy re-modelling of clay adjusted concept models into new 3D models for next stage processing (our technology at that time did not allow this).

Reflections on the observations

Merleau-Ponty in *Phénoménologie de la perception* [13] builds on Husserl and holds that our prime access to our 'lifeworlds' is created through bodily sense perceptions such as seeing, hearing, touching and smelling – and that our perceptive experiences structure the basis for our ability to "form things through the knowledge which sits in our hands" [10]. He rejects Cartesian dualism of body and mind and suggests a third form of 'existence'- (le corps propre) - situated between the two and in essence 'pre-subjective' and 'pre-objective'. Here the expressed (inner meaning, spirit) cannot be separated from the expression (body, signs, language). But also 'the other's' (the collaborating stakeholder's) existence falls between subject and object. Thereby the world of perception can exceed the individual I who perceives, and the other's perspective can therefore transgress mine. Human social and historical *practice* then forms a 'between-world' (*inter-monde*) between things and minds and between the participating human beings – but all based upon engaged and immediate bodily perceptions before any reflection has taken place [ibid: 334-338].

In Figure 3 such an individual is pictured within an ellipse and in Figure 4, three subjects collaborating towards a shared object from different perspectives are pictured as 'petals' of a flowerlike model. In the center the shared 'between-world' of the actors depicts the stage where 'the battle of interaction' is taking place – where the individual subjects try to come to terms with their own contributions (their objects) to the shared goal, but where *simultaneously* their individual objects must be harmonised in relation to the shared object of which the individual objects are integral parts.
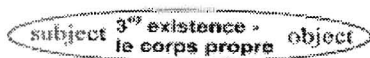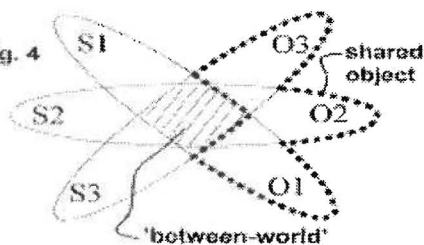

Fig. 3

Fig. 4

To this researcher such a model portrays the negotiated observations. In product development immaterial objects as a rule also have material implications and can be modelled. In our cases the immediate perceptions of physical object suggestions seem to catalyse individual

and shared reflective evaluations of emerging possibilities. According to Merleau-Ponty such individual and shared perception can transcend subjects and objects and create a world of immediate understanding (learning). If this is a reality, we can in such a procedure envision an approach to overcome the well-known obstacles of conflicting positions in collaborative design. If such physically based evaluations are arranged as RP-supported iterations, shared learning from the physical experiments can be achieved stepwise in a way where sense-based knowledge from one experiment (as opposed to traditional theoretical assumptions) can be systematically applied to the next. Thereby the development of product concepts could be based upon a strategy of *emergence* rather than of *preconception*. Such a realization can be seen as an elongation of the findings of Ehn, Brandt and Lerdahl, where their basic principles are extended into a landscape of higher concept sophistication and therefore higher potential of learning.

RP-supported fast and cheap physical modelling opens for the possibility of playing with and testing out 'wild' ideas in reality. The argument that creativity belongs primarily in early project phases is countered by the perceived realisation that mind/body experiences of later phases also stimulate imaginative searches for alternatives through alternations between bodily experience and mindful reflection. Radical concepts will frequently generate breakdowns in physically tested reality, which represent valuable sources for creativity because they inspire searches for new ways of tackling the experienced problems [20, 11]. This can be seen as an opportunity to establish an RP-supported strategy as a tool for exploration of creative solutions through provoked breakdowns through staging of arranged *playground* surroundings, supported by well-adapted technological tools.

The observed effects of the alternation pattern between concept models and clay further seems to be of vital importance. Since concept models offer possibilities of manual or tool supported subtraction (e.g. by grinding) or addition of material (for instance clay), I suggest that such procedures should be focused because they favour 'immediate sense feedback' to the designer(s) through view and touch – facilitating the 'ready-to-hand' (Heidegger) or *'le corps propre'* (Merleau-Ponty) experiences. If this result is rapidly copied and adjusted for undesirable surface imperfections, it will offer a valuable point of departure for the following iteration – eliminating computer screen alienation. As our copying technology was a robot arm/software-combination for digitalisation of the physical models, the detailed re-making of 3D models was found to be time-consuming and rough. Based on reflective observations, we sought,

found and acquired a fast optical scanner/software-combination from Minolta/Rapidform with appropriate manipulation characteristics. This is presently being tested in student projects which seem to support our assumptions, but results at the time of writing are too premature to be conclusive.

Playing Physical Iteration Games

Anti-dualistic approaches to collaborative design have been exposed in Ehn's and Brandt/Gunnet's focused concepts 'design-by-doing', 'ready-to-hand' use, 'hands-on-experience', 'things to think with' and 'things to act with'. Their and my findings illuminate the importance of *physicality* for elicitation of mind/body experiences in design action. It has also been shown that an RP-supported *iteration* approach has a dynamic character. The remaining issue is *play*, for elicitation of creativity, as argued. It is here thus suggested that a procedure involving the necessary elements for collaborative emergence of product concepts can be seen as a *Physical Iteration Game*.

'Physical iteration games' are integrated in the 'language games' of collaborative design. In iterative cycles of physical modelling, sense-based perception of the models, negotiative reflections based on the perceptions and re-modelling based on acquired shared object based knowledge, the collaborating actors *experience* through their objective bodies *and* subjective minds the emergence of their shared physical object – the negotiated artefact (see Figure 5).

In early phases the produced representations should be vague and abstract stimulating imaginationand diversity (see Ehn, Brandt and Lerdahl) but as concepts grow more concrete, RP/scanning-supported 'physical iteration games' can be intensively played more or less 'radically' depending upon individual preconditions or creative ambitions. The games seem to converge different perspectives of rationality and intuition in repeated attempts of mind/body reconciliations of 'word-based' and 'sense-based' languages of the stakeholders.

As the iteratively emerging physical representations produced in this way only eventually will end up as 'prototypes', I will suggest calling them by a more appropriate name: *Negotiotypes*.

Fig. 5
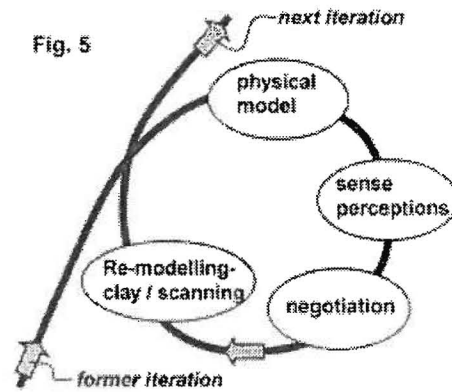
In addition to the described contribution in the conceptualisation and prototyping phases - to what extent can an RP-based communication approach be useful in early and/or late phases of a product development project? I will end this paper by simply referring to our suggested conclusions. Interesting communicative opportunities of RP/Rapid Tooling (RT)-supported modelling of radical concepts were identified a) in the ' Fuzzy Front End' of a design project - where different understandings of *visions* between decision-makers and inventors can be communicated through early physical modelling and b) in the 'Market Feedback' phase - where Rapid Tooling- supported production of test series can lower risk and communicate acceptance or rejection by the future users.

According to Fowler's dictionary a *type* is "a thing serving as illustration, symbol, prophetic similitude, or characteristic specimen of another thing or class" - a definition which applies well to physical models aimed at communication of emerging possibilities. Since physical typing according to our findings has interesting potentials for application in many phases of product design procedures, I have suggested the following concepts:

Visiotyping (Fuzzy Front End), *Negotiotyping* (Conceptualisation), Prototyping as established (Evaluation) and *Seriotyping* (Market Feedback). Seen in a totality these extensions to present product design terminology may serve to illuminate the possibilities opened up by employment of RP/RT technology as a tool for elicitation of design team communication. A concept embracing the whole process could be: *Rapid Multityping*.

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