Learning through Smart Wheelchairs

A formative evaluation of the effective use of the CALL Centre's Smart Wheelchairs as part of children's emerging mobility, communication, education, and personal development.

Final Report

CALL Centre
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Overview and Summary of Conclusions

CALL's Smart Wheelchair is an augmentative mobility aid. Like augmentative communication systems, it accepts a variety of different controls, tailored to the rider's needs, and complements the rider's efforts by expanding and interpreting their limited control commands to provide safe transit. Meanwhile (and also like augmentative writing and communication aids), the Smart Wheelchair gives appropriate feedback, and shares in decision making about mobility issues. *Unlike* robotic systems, it does not act autonomously. The aim is to complement and extend the user's abilities, not replace them. The ideal situation is one in which the Smart Wheelchair's help is less and less needed as the child develops, and their own control grows to replace that of the Smart Wheelchair. Sometimes the ideal is not achieved, and the child's development reaches a plateau. At these times, the Smart Wheelchair setup is 'frozen', and the child uses the mobility configuration s/he *can* control, as part of daily living.

Because the Smart Wheelchair was developed in a centre specialising in Computer-based-learning (CBL) and communication aids, its designers were sensitive to the need to overlap and complement other augmentative and learning technologies. The Smart Wheelchair was designed from the outset to link to other computers and communication aids, and has features which are aimed at improving learning and communication skills other than those purely associated with mobility. For instance, the Smart Wheelchair carries a speech synthesiser, one role of which is to engage in a decision-making dialogue with the rider; the chair can act as a sit-on-turtle for LOGO-graphics work; and the control systems can be used to link to other learning aids.

The Smart Wheelchair is not a single entity: there are as many Smart Wheelchair variants as users. Just like the more complex communication aids, any particular chair is a collection of components, tailored to meet individual needs, and typically subject to continuous review and revision. A Smart Wheelchair could be set up for a rider only able to operate a single switch, relying on chair bumper-sensors to deal with obstacles, thus sharing the workload with the rider. This chair might use a speech synthesiser to tell the rider what is happening. Or a Smart Wheelchair could be configured as a line-follower, able to steer the user along lines marked on the floor. Or a Smart Wheelchair might not take its orders directly from the rider, but instead respond to commands built into their portable communication aid. We outline the evolution of the Smart Wheelchair in section one, relating its design to research findings, and return in section three to how the current Smart Wheelchair operates.

This report is about the introduction of twelve Smart Wheelchairs into three Edinburgh based special schools, and their trials by a number of children with special needs.

The evaluators had three objectives. The first was to help the design team report to their funders on the value of their investment in the Smart Wheelchair programme in improving child development. We wanted to know how effective the Smart Wheelchair was in opening new motivation, mobility, and communication opportunities for children with a range of different ages and disabilities, in a variety of settings, and how these changes in opportunity affected children's development. We also tasked ourselves with providing the technical team with formative advice during the chair's development. Finally we aimed to distil effective practices into guidance materials for future chair users, and to assess and refine these materials during the project.

'Effectiveness' is a context-dependent notion which depends on many factors. The most obvious are the Smart Wheelchair systems themselves, and each individual child's reaction to them. However, where technological change is mixed with curriculum development, where intervention crosses therapeutic and teaching boundaries, and where these experiments take place in times of educational austerity and turbulence, technical and child-based issues are by no means guaranteed to predominate. We therefore also wanted to probe the environmental preconditions for success, and to suggest ways which would maximise these during the transition to full production of the Smart Wheelchair, and beyond.

To understand the kinds of environmental and individual factors during those continuous cycles of assessment and intervention which typify the use of complex augmentative systems implies observing and recording many facets of rider behaviour. Some of these are product measures - identifying what has changed, and estimating the degree to which this change can be attributed to the Smart Wheelchair work. Some measures focus on processes: how children's behaviour changes, and how their support system responds. In a formative evaluation such as ours, where researchers are active partners in the processes they are measuring, the act of observation cannot help but be intrusive, and will itself affect the outcome. In this case, the problem is particularly acute since the evaluation team are responsible for providing some of the school-based support and training, and for developing some of the written products. Section two focusses on the evaluation aspects.

Section three (Setting the Scene) introduces the Smart Wheelchair design, the children, their surroundings and the people they interact with, and the project and evaluation process itself.

Section four presents case studies of all the children involved in the project. In section five (Discussion of Results), we draw together some of the most important findings and discuss their implications.

In order to keep this report short, we have relegated much detail to annexes, which cover the materials we have produced, hardware and software descriptions, evaluation procedures, and process and product measurements. Section six outlines the disseminable products among these, identifying which are now ready for broader distribution, and section seven extrapolates our results to the future introduction of the Smart Chair into general service, commenting on the role of formative evaluation itself in the design of other new technology for special needs. Finally, section eight draws such conclusions as we can, and makes suggestions about future work.

The formative model used for this project has succeeded in its objectives of generating both practical products and research findings, and in laying the foundations of sustained dissemination efforts.

Product outcomes include

- Improvements in the design of the Smart Wheelchair
- Training courses of various levels, with associated materials
- Assessment procedures, and associated literature
- Curricular materials

Our main research findings are

- **Safety:** The Smart Wheelchair is a safe learning environment for physically, cognitively and perceptually impaired children. We have recorded no regression in condition or over-dependency. On the contrary, it encourages improvements in the areas outlined below.
- **Motivation:** Smart Wheelchairs and the mobility they promote can be effective motivators in situations where other stimuli have failed. Improvements have been recorded in children of all ages, with various conditions affecting their mobility and ability to control conventional powered wheelchairs.
- **Developmental improvements:** This motivation can be exploited to develop mobility itself, assertiveness, exploratory behaviour, and persistence. Initiation improves in both interpersonal, and person-to-chair interactions. Secondary benefits of these improvements include the opening up of better functional environments for communication and learning; and improvements in physical tone and control.
- **Transferability of skills:** The skills needed to operate a Smart Wheelchair are transferable to other situations. Specific skills associated with control, attention, and scanning in the Smart Wheelchair are close enough analogues to those in other augmentative systems for them to be useful bases for development.
- **Training for conventional powered chairs:** Smart Wheelchairs can also be used as effective transitional training aids en-route to conventional powered wheelchairs, for those children for whom the initial step to analogue control is too great, or where there is doubt about other driving-related abilities such as concentration, vision, or the ability to estimate and plan.
- **Most effective environments:** Complex system technologies like the Smart Wheelchair show most benefit when they are used as integral parts of a broad curricular design. Occasional use is unrewarding. Sharing chairs leads to counterproductive timetabling problems, and lack of perceived worth by the rider of a non-owned resource.
- **Time-on-task:** More variability in the responses of the children on the programme can be attributed to lack of opportunity to practice due to non-integration with other activities than to individual differences in abilities: we make specific proposals on how to promote better integration.
- **System design:** The Smart Wheelchair itself is flexible and robust. Future development should concentrate on enhanced tools for transition in more complex environments beyond school, and into improved integration with other aids. Specific attention is needed to enhance collision sensor life.
- **Supply, support and service:** There is a market for Smart Wheelchairs, but it is complex. To be effective, supply, training, assessment, seat and control tailoring, and long term support must all reflect the unique nature of each chair and user, and the developmental stage they have reached. Over the product life, support costs will be far greater than hardware costs. Such a situation is common in other tailorable systems (such as commercial computer systems), but rarely understood in the context of mobility systems, and difficult to put into place under current Health Service and Educational provision. A possible strategy for service provision would be to build on and extend the expertise of existing regional centres, including augmentative communication centres, supporting this extension through initial training, assessment packs and loans.

1. Introduction

1.1 Preamble

New technology in special education predominantly has come to mean one of two things: augmentative systems, or computer-based-learning. Augmentative systems include communication and writing aids, access tools for visually impaired pupils, and other tools bridging into the curriculum. Computer-based-learning (CBL) encompasses programs for exploration, creative activities, and play, as well as more conventional computer aided teaching packages. As both augmentative systems and CBL are based on computers, and use many of the same specialised control systems (like switches and speech synthesis), there has been much scope for overlap and cross-fertilisation, and it is sometimes difficult to separate augmentative access tools from CBL packages.

There is an underlying theme to both CBL and augmentative tools. Both aim to increase access to learning opportunities by allowing computers to take over some of the physical, cognitive, or communicative tasks which could block broader social acts and the developments which grow from them. Some, but not all. The objective is to ensure that the machine enables the child, but does not take over from her.

A recurring comment from evaluators of such new technology is how motivating it is. Sometimes this statement is misinterpreted. There is nothing intrinsically motivating in a computer, or even a program running on one. What *is* motivating is the autonomy and power which augmentative access systems give to otherwise disenfranchised children.

The Smart Wheelchair team built on these observations. They argued that if increased independence in interpersonal communication and control of CBL are motivating, then so should be increased freedom to move independently. If exploring computer-based 'worlds' is exciting, then exploring the real world should be even more so. Computers made the CBL user's explorations safe: they should be able to do the same thing for wheelchair riders. The Smart Wheelchair is the result.

Smart Wheelchair 04

Augmentative systems for communication replace poor channels of communication and control by others, sometimes directly, but more often through intermediate systems of symbolised choices and selection mechanisms. The problems facing a team who want to use such techniques in mobility are complex: control of a dynamic system through the normal, very slow, augmentative techniques simply exacerbates problems of potential driving inaccuracy, collision, and even danger. We shall shortly outline how a Smart Wheelchair overcomes these problems.

However, this CALL Centre project builds on the experiences and experiments of others, and on early work with early prototypes by CALL staff. We are not by any means the first to note the motivating character of mobility, or to record the detrimental effects on a broad spectrum of developmental features which lack of mobility engenders. There is a rapidly increasing number of studies which show this to be the case. Before describing the current Smart Wheelchair programme and what is now involved in a Smart Wheelchair design, we will look at some related research, and review CALL's early prototype Smart Wheelchair projects.

1.2 The Case for Augmented Mobility

Augmented powered mobility can affect four broad areas of development: learning, communication, motivation and mobility. Improvements in these will in turn affect social and educational opportunity. Evidence comes from three sources:

- through research into the importance of control and mobility in early development, and the effects on control of other augmentative systems and technologies;
- from research on the effects of un-augmented, conventional powered mobility on development of learning, communication, motivation and mobility;
- from the work of those seeking to apply powered mobility-based benefits to the development of personality, socialisation and perception.

1.2.1 Non-wheelchair research

Learning

Over the past three decades a wealth of evidence has accrued to show the positive effects which come when children, even young infants, have the chance to gain control over their environment, and how that control is severely impaired in the non-ambulant child.

Attempts at control start well before good physical skills are developed. In the world of infancy, Watson (1966) was first to question the ontogeny of the *smile*. He argued that the development of the smile in infants could be explained by attempts by the infant to gain control over his social world i.e. his parents. It was a simple step to extend this theory into far-reaching domains, arguing for the key role of 'learning to learn'. From these roots was derived much of the work on 'learned helplessness', depression and passivity.

One of the central aims of the Smart Wheelchair is to present opportunities - sometimes the only opportunities - for a severely disabled child to gain control over his world, and thereby to learn that new tasks can be approached with an expectation of success, rather than failure.

Communication

Augmentative communication systems based on electronic technologies have, in just a few years, changed the way in which young non-speaking children are viewed by society, the schooling that they will receive and the social interactions that they can initiate and sustain in the community.

At every point in the spectrum of communicative competence, augmentative communication technologies have been used to positive effect. We believe that some of the key elements of augmentative systems for communication have much similarity to powered wheelchairs as augmentative systems for mobility. Indeed, one of the basic premises of the Smart Wheelchair is to exploit mobility to underpin other areas of the curriculum, drawing on similarities between competences needed for mobility and those needed for communication. McDonald and Rendle characterised communicative competence by the figure overleaf.

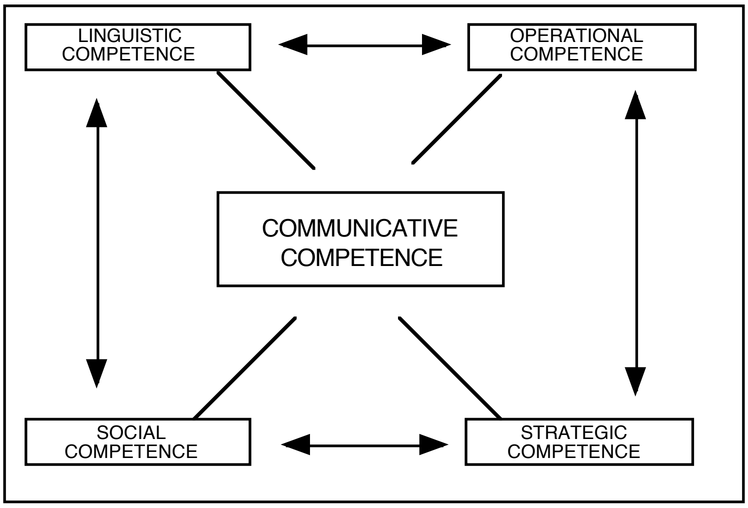


Figure. Areas of communicative competence (after Light, 1989; MacDonald & Rendle, 1992).

Our claim is that competences in the four interrelated skill areas needed for effective use of an augmentative communication aid can be enhanced by concurrent use of augmented mobility. Operationally, children develop new control skills. Strategically, planning, turntaking and problem-solving skills developed whilst driving may transfer to augmentative communication aid use, particularly if the two environments can be made similar (or, as in the case of the Smart Wheelchair, one and the same). Linguistically, the opportunity to choose new communication situations, and initiate in them enhances the range and use of vocabulary: being mobile gives you something to talk about. Socially, moving autonomously in a wider school environment with other children will promote social skills.

Perception and its development

Campos and his colleagues (e.g. Campos & Bertenthal, 1987) drew together the results of their own and other researchers to highlight the importance of self-produced locomotion. For instance, using the visual cliff paradigm, they showed that self-produced locomotion gives a greater degree of visual and vestibular feedback. Some have argued that self-produced locomotion plays a central role in the development of spatial orientation (e.g. Gibson & Spelke, 1983). What is much less clear is whether 'self-produced locomotion' might be equated with augmented mobility.

1.2.2 Wheelchair-related research

A number of studies using conventional powered wheelchairs have investigated the effects of powered mobility on children's broad development. The results have shown that experience of powered mobility *does* benefit non-ambulant children in similar ways to self-produced locomotion in ambulant children. The effects are probably less since the benefits of mobility are very likely to be related to the degree of independence: wheelchair movement is obviously more limiting than normal mobility.

Learning

Douglas and Ryan (1987) describe a single case study in which a 4.5 year old boy who had suffered a C4 neck injury was provided with a powered wheelchair controlled via mouth joystick. Improvements in: confidence; language; understanding of object permanence and solidity; peer interaction; initiation and curiosity; perceptual awareness; and visual memory were noted.

Communication

Butler (1986) attempted to measure whether independent mobility via powered wheelchairs would have a positive effect on: number of interactions with objects and people; changes of location; and self-initiated communication. Six children aged between 23 and 38 months were involved in a study lasting 10 days. Behaviours were recorded using videos and later transcribed. The results as a whole did not support all hypotheses (and this seems reasonable given the length of the intervention), but positive gains occurred for all the children in different aspects of behaviour. For example, while changes in location increased from between 30% to 200%, self-initiated communications actually *decreased* in one of the children, because he no longer had to ask to be moved to other locations.

Motivation and Mobility

The improvements reported above rest on two main determinants: the motivation to use a wheelchair; and the power and control achieved through mobility. From these, all other benefits flow. The aim therefore in using powered mobility aids with children is to maximise the child's motivation, both extrinsic and intrinsic, and degree of independent mobility to encourage optimum wider developmental improvements.

1.2.3 Wheelchair related research extending into other areas of development

Psychosocial development

A more holistic view of the child can be seen in the work of Karin Paulsson & Maria Christoffersen in Sweden. Rather than restricting their aims to reduction or compensation for physical limitations of their children, they set out to discover if independent powered mobility could influence in a positive way the social, emotional and cognitive/intellectual development of physically disabled school children (2.5 to 5 years old).

To test this they adopted an Eriksonnian framework, in which it is thought that children around 1-2 years of age begin to develop a sense of independence, acquiring a concept of self. Paulsson & Christoffersen hypothesised that, given an opportunity for independent mobility, disabled children would have improved psychosocial development. And that through this they would come to have a higher status among other children. They felt there would be higher status because of research showing that children who are helped a great deal by adults are less accepted by their peers.

One of their results was that, according to parents, their children showed increased self-confidence and a gaining of physical and psychological independence. Their relationship to other children was also changed. The disabled children acquired a higher status among their peers when driving their powered vehicles. Not only the disabled child but the whole of the family was regarded as more 'normal'.

Vision and perception

Staff at St. Paul's School for the Blind and Visually Impaired in Australia have worked with powered wheelchairs with multiply disabled, visually impaired children (Peck & Whiting, 1988). They report similar results to those found by other researchers: improvements in self-esteem, peer status, curiosity, hand-eye coordination and speech. They found that children with visual acuity of 3/60 could drive as effectively as children with visual acuity of 6/60 in familiar environments where known 'landmarks' could be identified, and that the demands placed on children's residual vision improved functional vision, posture and concentration.

1.3 The CALL Smart Wheelchair Approach and Early Designs

These studies, together with CALL's experiences, set the agenda for our programme of work. Although mobility was in and of itself an important aspect of the projects, we hoped to provide an integrated system which could build on this mobility to encourage learning, communication, motivation and social interaction.

CALL's current Smart Wheelchair designs are based on two early prototypes. They have evolved features to help riders and their carers use them effectively as part of a broad education, and are influenced by the studies above and CALL's experiences with other augmentative communication and writing systems.

1.3.1 The first prototype (1987)

The prototype Smart Wheelchair was designed and built by CALL and the Bioengineering Centre, Edinburgh in 1987 to investigate the possible benefits and applications of augmentative control in providing severely disabled children with access to some degree of independent mobility (Nisbet et al, 1988). The design grew in part out of the CALL Centre's service and research work in providing support to children, parents and professionals using augmentative communication aids and computer-based learning systems. We had found that even quite limited mobility (using an earlier powered 'Unibuggy' developed at Hull University in England) could motivate our young switch users to use and practice with their controls and, importantly for their concentration and effort, to have fun doing so. This impression was supported by other studies using ordinary powered mobility aids by researchers such as Butler, Verburg, and Paulsson who had found that use of a powered mobility aid had a beneficial effect upon many aspects of a non-mobile child's life other than simply mobility.

However, CALL's aims went beyond the use of commercial wheelchairs, in that we assumed that our users would be children who could not control a standard powered mobility aid for physical, cognitive or perceptual reasons. Therefore the powered wheelchair itself would have to be intelligent enough to

- recognise and cope with dangerous situations and
- enhance the mobility experience for the pilot.

Much was being made at the time of autonomous transportation systems, which would move people with no driver control (and work continues in some projects at the time of writing). We did *not* want to build an autonomous robot as this would have little educational or developmental (or, in our opinion, human) value. Our interest was in exploiting the motivation which we suspected was inherent in even quite limited mobility, to encourage development of physical skills (especially switch and control use); curiosity and exploratory behaviour; communicative initiative and play. We hypothesised that we could reduce passivity by careful introduction of mobility-based, positive experiences.

We initially believed we could buy the system we needed, and set about specifying the range of facilities which we envisaged as being necessary for such a vehicle. As it became apparent that even the most advanced wheelchairs were not suitable, the two Centres decided to build one, founded on CALL's understanding of augmentative systems, and PMR Bioengineering's experience with the design of modular solutions to mobility problems.

We saw little virtue in designing either wheelchair chassis or motor controller when many already existed. The system was therefore based upon a commercially available chassis and controller (an Everest and Jennings Elite), with the *Smart Controller* electronics connecting in place of the standard joystick, an approach we continue to employ. In principle then, smart controllers can be fitted to most wheelchair chassis which are operated through an ordinary motor controller, subject to the necessary mechanical and (perhaps) electronic modifications.

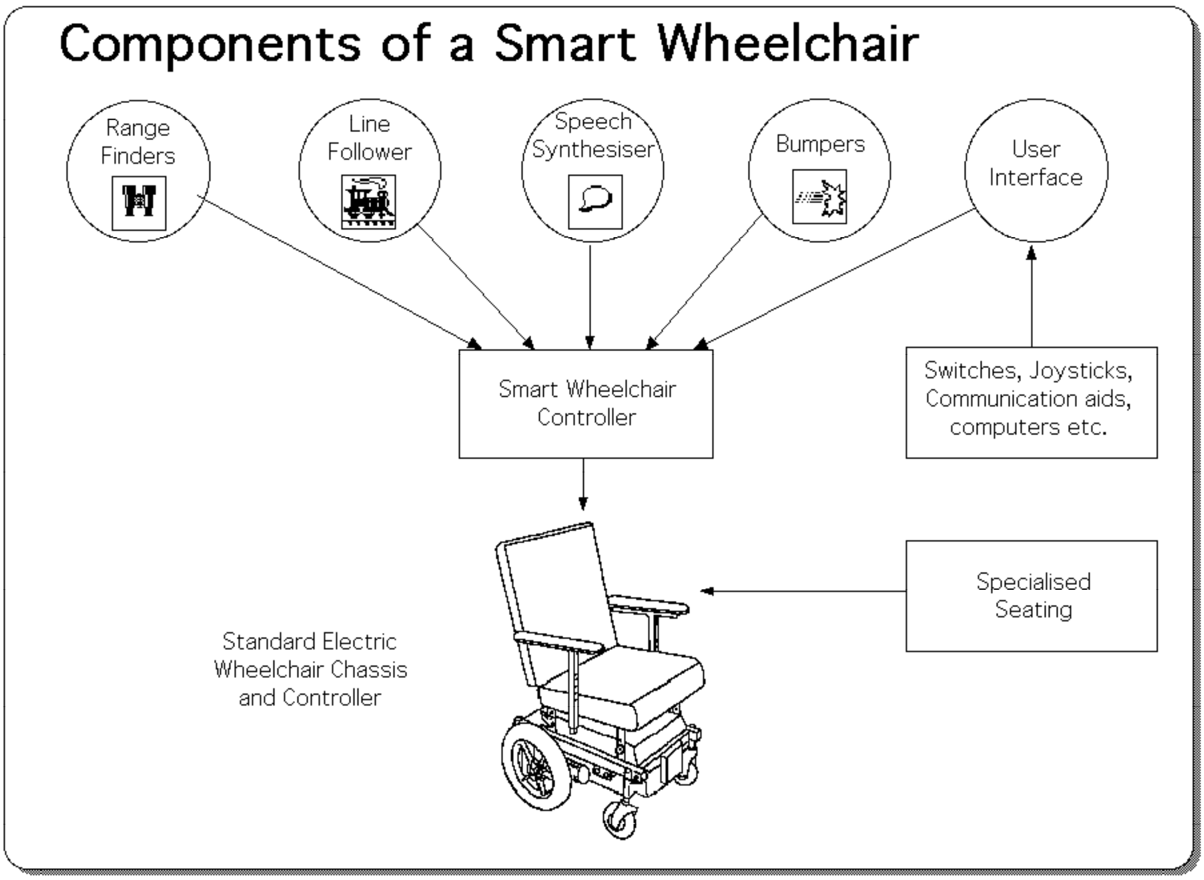
Our initial specification called for a wide variety of possible user interfaces and chair based facilities. However, our experiences with communication aids, computer-based learning systems and other classroom technology had shown that a severe barrier to adoption of many systems was poor human/system interface design. This is especially difficult where the system is to be used by a child whose experiences and understanding are limited, and where there are many possible permutations and combinations of facilities, depending on individual needs and circumstances.

It was essential that the technology be simple to understand and use, and predictable for both teacher/parent/carer and child. This led to three major design principles:

- division of the various chair functions into different 'tools', each of which performs a single, easily understandable function
- ability to mix these in relatively unconstrained ways with no unexpected combinatorial effects, and
- mode free operation.

Tool based representation of functions allows users to visualise and reason about the chair's functions in non-technical language. *Mix-and-match without surprise interaction* is essential if a child's effort in learning a given function is not to be lost at the next modification of the system. *Mode-free design* implies that any control which has been included in the system can be used at any time: there should be no occasions when the user has to think 'have I got that ability in this mode?'.

The user's view of the system as designed at that time looked like the figure below: the design remains essentially similar to date. (We return to the current Smart Wheelchair design in section 3.) The interested reader is referred to the User Handbook for more on the user perception of the current Wheelchair: technical details can be found in the sister report to this, prepared for the Scottish Home and Health Department (CALL 1994*K/RED/C104*).



- *User Tools*
  The prototype could be controlled with one to five simple switches (such as those normally utilised with communication aids, computers or other assistive devices); a switch-operated five way scanner; the standard proportional joystick; or an augmentative communication aid or laptop computer (via an RS-232 link).
- *Motion Tools*
  Prior experience of assessing children for switches emphasised that different children required different types or switch operation and so three were provided on the wheelchair: 'Timed', 'Momentary' and 'Latched' control. We will return to describe these in detail later.
- *Bump Tools*
  As the chair, by definition, would be used by novice inexperienced pilots, we added collision sensors to halt the chair on collision and, if necessary, do something to help the pilot get out of trouble: these facilities we dubbed 'bump tools' and comprised 'Bump and Stop', 'Bump and Back Off', and 'Bump and Turn'.
- *Listen Tool*
  It was possible to programme the wheelchair (via an RS-232 communications port) to carry out planned sequences of movements (using a standard LOGO syntax) for storage in the communication aid or laptop computer.
- *Advanced Tools*
  In the original specification we also identified the potential of line follower and proximity sensing systems, but we wished to gain some practical experience of the real problems associated with the general concept before putting large resources into technical development. Therefore, the prototype was delivered to a school with collision sensors only.
- *The Observer*
  A major aim was to develop skills which could be transferred to the use of other technologies such as communication aids. To help in this transfer, we wished to build in communicative functions and, if possible, integrate the use of communication aids to the use of the chair. The 'Listen' tool mentioned earlier enabled the user to pass instructions to the chair with a communication aid: in return, we provided a means for the chair to communicate back to the user (or to the world at large) by means of a speech synthesiser - the Observer tool (textual or graphical interfaces are also possible). Originally, we envisaged this as a communicative device but we found that some children appeared to find it helpful when using the chair, to reinforce and explain the chair's actions.

Effective interaction is the key to using any technological system, and is the fundamental link between communication skills and chair skills. The Observer and its speech synthesiser play an important role, which is worth elaborating on.

Although the Observer's language was fairly primitive, it appeared quite valuable for early switch users establishing cause and effect with timed control over the chair, (although for experienced users, spoken confirmation of all chair movements was undoubtedly a nuisance and it was important to be able to turn it off). However, the Observer had other advantages. It confirmed tool selection for all users of the chair - child, parent and staff. Its continual reporting of what the software is doing (or not doing!) made it useful in fault finding; and it helped the user understand how the boundary of control between the chair and pilot shifted, especially after collisions and, in the more recent systems, during the capture and release of line following.

Possibly most important is the Observer's use with less intuitive tools such as those based upon non-contact proximity sensors. It could be argued that a collision is such a solid, concrete event (sometimes literally) that most users will make the connection between the jolt of the impact and the subsequent wheelchair action without help from a speech synthesiser. However, this is less likely with non-contact sensing systems which might try to guide the chair gradually away from obstacles or stop it some distance from the obstacle. The Observer could help to answer questions like - 'why is the chair stopping?' and ' why can't I get over there?'.

1.3.2 Experiences with the first prototype

Westerlea School staff collaborated in the evaluation and use of the prototype. They identified four children whom they thought might benefit from using the chair, and collaborated in preparing a programme of work for each.

All four children had already been using specialised computer software for early communication or learning, operated by large 'hit' switches or squeeze grip switches. These controls were transferred to the chair for the early sessions. Initial sessions simply concentrated on letting the children experience movement using this switch, normally with timed control. Timed control avoided the possibility of the chair getting out of control if the child could not release the control after initiating a move. The second stage involved steering, either using another switch, or allowing the chair to decide on a new direction after a collision, using the 'Bump and Turn' tool. One child used both steering techniques - his set up employed forward and left turn switches with 'Bump and Turn' to the right, which gave him reasonable independence. The chair was used in a wide range of games and classroom activities: traffic games; hide and seek; pretend 'postman' play; 'one-touch' football between two wheelchair users; 'what's the time Mr. Wolf'; slalom driving; as well as general mobility use around the school.

Again, while the attainment of full independent mobility was not the central aim there seemed to be no doubt that the two children who developed greater independence also showed improved socialisation, self-confidence and curiosity.

The prototype chair has been in constant use in Westerlea School since its introduction in 1987, mainly in the speech therapy department where it is used in a 'Mobility Language Group' - a mixed group of self-locomoting, manual, powered and smart wheelchair users.

Two of the users developed new skills at a rate which seemed unusual given their previous progress, but the other two, whilst making progress, did not show the same spectacular improvements. Reasons for this were unclear, given the variety of differences in age, sex, baseline skills, home and school environment, staff intervention techniques and styles, motivation or lack of it and so on. It was to investigate the effects of these various factors and more importantly, to learn how to manage them that we applied for funding to construct and evaluate more smart wheelchairs.

1.3.3 The second prototype

The second prototype was built in 1989 for a young man in a residential hospital, as part of a communication programme. A. has severe spastic quadriplegia, some dysarthric speech, and limited gross control over one arm. Some concern was expressed over his vision and perception, but this had not been assessed. He lives in a special care ward within the hospital, apart from occasional weekend visits home to his father or to his aunt. He is sociable but has little to occupy his time. He was originally referred to CALL for assessment for a communication aid, and the Smart Wheelchair was offered to help develop switch use and to provide greater independence and communicative scope should an augmentative communication aid prove useful.

This time, the Smart Wheelchair was based upon a National Health Service chassis and motor controller, again with the smart electronics replacing the joystick. The specification was identical to the previous chair, except for the addition of twin ultrasonic Rangefinders to slow the chair down (the 'SlowDown' tool) as it approached obstacles (a major concern of the ward staff was the safety of other residents who often lay around the floor). A. started off using a switched joystick, gated for forward movement only, with the intention of adding more directions of movement as his skills improved. The chair was less reliable than the first mainly due to problems with batteries and the interface between the smart and motor controllers, and a more serious constraint upon progress was the lack of staff time, either from CALL, or from the ward, to provide A. with practice sessions. The combination of these two factors meant that progress was very slow indeed compared to the school users. The new 'SlowDown' tool seemed to be useful for giving A. more time to react to incipient obstacles, and certainly reduced the impact of the eventual collision (the speed reduction it provides is not intended to stop the pilot getting to where he or she wishes to be, only stop them hitting it quite so hard).

At the end of 1990/91, CALL's funding arrangements changed and the work with the second prototype had to end. However, in October 1992 the ward again contacted CALL to report that a full staff team was finally in place and to enquire about restarting chair based work. Since funding is not available, CALL staff are supporting A. and his carers in marginal time.

1.3.4 Conclusions on the prototype designs

The prototypes influenced the design of the new Smart Wheelchair in several ways.

- *The tools metaphor*
  Feedback from the school staff emphasised that the usefulness of the chair depended heavily upon practical considerations, such as ease of setting up for different children and reliability: if a teacher had 30 minutes timetabled for a Smart Wheelchair session, it was no use spending half that setting up the chair parameters.

  The tools metaphor was judged to be helpful for configuring the chair both by the design team and by users and staff, and was retained: design effort was put into improving methods for selecting tools, and configuration of other chair parameters such as speed and turn angles.
- *Bump tools*
  The collision sensors and tools based on them proved helpful especially in the earlier stages of training. As children developed their control skills, the electronic collision tools became less used. Even at that stage, when all the bump tools were switched off, the bumpers themselves were extremely effective for guiding the chair through doorways or along corridors after a child misjudged an angle of approach. Such usage was physically punishing though, and reliability of the bumpers was a problem.
- *Motion tools*
  'Timed' and 'Momentary' tools were popular. The 'Latched' tool was less so, although the school staff felt it was important to have the option of all three.
- *User tools*
  Probably the single most valuable aspect of the design from the staff's point of view was being able to plug in standard switches already available in the school. Control via communication aid or laptop computer was not required as none of the children used such technology.
- *Seat and control adaptability*
  Although the team hoped that second generation Smart Wheelchairs would not be shared to the extent that the prototype had been, the difficulties of rapid adaptation of seat and controls was given much attention, and the seating system was redesigned as a self-contained module.
- *Robustness, maintainability, reliability and ease of extension*
  The prototype Smart Wheelchair had proved reasonably robust, with the exception of the bumpers: however, the electronics were not designed for ease of maintenance, and could not easily adapt to changes in technology (such as newly available cheaper microprocessors, or emerging powered wheelchair interconnection standards). A complete redesign of electronics, software, and hardware was undertaken, emphasising modularity and maintainability. The bumpers were also redesigned.

1.3.5 Second Generation Smart Wheelchairs (1991 to 1993)

To summarise: these early studies helped define the specification for the current Smart Wheelchair design. We specified a very flexible system, able to take a wide variety of controls and able to use them in several mobility modes. It should retain and extend the design principles of shared control and mode-free operation, and should provide good feedback to rider and others. It should be safe, easy to set up, and robust. The chair should integrate well with new communication systems, and should be controllable from external computer systems.

This new design was also to lend itself to transition to manufacture in quantity. In this respect, it was to be modular, as cheap as possible, and able to migrate across new technologies and standards as they emerged.

Just as importantly, the prototypes influenced the design of the associated evaluation. Technically, there were no contentious issues: the chair had to be tested against the new specification in a way which allowed changes to be incorporated during the project itself. However, the range of applications we were to investigate posed more problems.

The research studies outlined throughout this section indicate the wide ranging and powerful effects of mobility on learning, communication, motivation and social interaction. We were convinced that studies which confined themselves to one single aspect (the most obvious being children's ability to use the chair purely for mobility) would miss the opportunity to understand and promote any resulting benefits in broader developmental contexts. Worse, by concentrating our efforts solely on improvements in driving ability and related skills, we would miss and perhaps even suppress the beneficial reciprocal effects of successes in learning, communication, motivation and social interaction on just those mobility skills. In short, we would not be taking a systems view of the development of the child.

Fortunately, our funding bodies were able to see that although our aims crossed traditional health/education boundaries, broad-based results would be likely to inform both parties, and were able to accommodate us in the design we outline next.

2. Formative Evaluation : Aims, Philosophy, Design, Tools and Limitations

We hope by now to have signalled our baseline position, namely that impaired mobility can have wide ranging and devastating effects on child development; that any augmentative systems built to alleviate those impairments can only be properly used as part of an integrated curriculum (including both teaching and therapy); and that these systems can only be tested against the broad developmental backdrop. In this context, mobility becomes mediated through interactive technology, and in that sense, is transformed into a branch of augmentative communication: studies must therefore include a transactional component. In our project proposal, we said this about use of a Smart Wheelchair:

"From our experiences with the Smart Wheelchair prototype, we believe that it offers rich opportunities to enhance the development and learning of young people. These opportunities include

- ***better assessment**: Whilst we are still interested in the opportunity to assess and train functional control of special input devices in motivating situations, we also see opportunities for communication-rich play and exploration which provide the basis for observation of other comparatively inaccessible functional and cognitive skills.*
- ***extension of communicative skills**: The Smart Chair can both receive control from and pass information back to other communication aids. The perceived dimensions of those communication systems can therefore be extended in the eyes of the child. Through this increased awareness, it will be possible to introduce such things as keyboard emulation skills which will in turn be necessary when the child is introduced to other non-human communicative partners like word processors, drawing tools, and computer-based learning programmes, all of which rely on augmentative tools for access.*
- ***computer-based learning opportunities**: The possibility of using the chair itself as a keyboard emulator, and of controlling the chair by an external computer, makes it feasible to involve both rider and chair in explorations of new parts of the curriculum which would again normally be denied to physically disabled pupils. One particular example we wish to explore is the use of the chair as a sit-on Turtle for LOGO programming, following Papert, Goldenberg, and work here in the CALL Centre*
- ***exploration, play, and socialisation**: The safety features of the chair make it possible for the child at risk of developing passive behaviours to become involved in the kind of social interactions which encourage a sense of personal autonomy and which hopefully will transfer into communicative assertiveness and a desire to initiate.*
- ***planning**: The interactive nature of the chair's operation makes it possible to set up situations in which the development of planning skills can be overtly observed and encouraged.*
- ***classroom observation**: Curriculum and training planning critically depend on close observation and continuous adaptation of the environment. The richness of the activities which can be undertaken through the chair, and its simple tailoring, make it a good platform for generating useful, observable behaviours. These can be complemented by on-board computer records of child/machine transactions taking place across the chair and its associated communication systems."*

Our evaluation issues were determined by these beliefs. They formed the basis for a series of specific, child-related questions on the usefulness and effectiveness of the Smart Wheelchair in assessment and observation of children; in planning for, and extending communication skills and opportunities; in providing the basis for curriculum-relevant CBL and early learning; in enhancing children's exploratory environment, enabling their play, encouraging their socialisation and, of course, providing augmentative mobility. Behind these outcome-related questions were more abstract ones addressing the motivational effects of augmentative mobility and the degree to which skills learned as part of improving mobility could be transferred to other areas of development.

As well as generating child-centred questions, the same beliefs also raised environmental, resource and support issues: what new skills were demanded of therapists and teachers (and how appropriate training might be provided); what changes to curriculum, therapies, other aids in use by the child, and the classroom itself might be needed to get the most out of augmentative mobility techniques; and what costs were involved. As we shall see later, cost estimates are not straightforward where dynamically changing systems such as the Smart Wheelchair are concerned.

2.1 Resources and Constraints

Really new technology is expensive to develop. By really new, we mean systems which cannot be bought off the shelf at reasonable cost, and simply reworked or recombined to create what is needed, but which need new component design, or new programming. The worst of all worlds occurs when the projected system calls for a mix of new electronics, new programming, and mechanical engineering.

CALL's Smart Wheelchair is really new technology. Although it builds on a commercial electric wheelchair chassis and controller, all else has had to be developed from scratch: new mechanical subassemblies for sensors, new interface and computing electronics, and the programming to go with them. This meant that the technical team's salary costs (although very modest, at less than two engineers) outweighed the costs of the actual chairs for the trials: the usual situation for prototype production.

Paradoxically, the expense was due to the team's aim of keeping target production costs down. It is not difficult to buy in expensive and fast controllers and sensors: many experimental robots are built in this way, and their price reflects it. The challenge was to build systems which would be cheap to produce after the experimentation was over, and to do so with the limited design and production resources available under the grants.

The result of this approach both helped and hindered the evaluation design. On the one hand, instead of one or two prototypes, the development team were able to produce twelve trial chairs. Two of these were to be kept back for spares and development, leaving ten for the evaluation. On the other (and notwithstanding that this is a creditably large number given the budget), it is still very small considering the number of potential uses to which the chair could be put, and the possible range of ages and needs of the children who might ride it. A complicating factor in this case was that the Smart Wheelchair is funded by agencies with widely differing interests. The Scottish Office Education Department was primarily concerned with the motivation and learning issues, whilst the Scottish Home and Health Department's interests lay in conventional mobility aspects.

For the development team, the problems were how to get the maximum breadth of experience with the chair during the trial, whilst retaining high quality observations; how to ensure that information was available to them during the evaluation (rather than ex-post-facto), to allow development and refinement to continue; and how to support the prototype chairs and their users throughout the research. They also wanted to avoid losing sight of those issues which crossed Health and Education boundaries, and thus were in danger of being under-promoted by either. These included exploring the relationships between communication, mobility and learning; and the integration of augmentative and learning systems.

The evaluation ambitions also had to match the human resources available: the evaluation team comprised 1.2 full time equivalent staff, and the engineering support for wheelchair design, build, assessment, tailoring and maintenance was less than two full-time-equivalent engineers.

Finally, the project had to plan for a series of staggered starts. All wheelchairs were to be built during the project period itself, necessitating a staggered production run which had to be timetabled to coordinate with the equally time-consuming work of individualisation and tailoring, later changes to those chairs already up and running, maintenance and repairs, and the school timetables. Even the latter was tricky: one of the three schools runs a 52-week school year, whilst the others take conventional holiday periods.

2.2 Formative design: Product-oriented, Self Critical, Continuous Appraisal

Evidence from other technology-based projects in computer learning and augmentative communication is that non-participant observation is not an effective use of scarce resources. There is no doubt that schools need support during development: equally, it is now unusual to find funding for both support team and independent assessor.

Moreover, one of our aims was to create and test courses, written materials in support of them, handbooks, and undertake other dissemination exercises. Again, it was unrealistic to expect independent production and evaluation.

Given the resources available to CALL's development and evaluation team, therefore, the most promising strategy to begin to address the issues above was to mount a multi-school-based formative evaluation, using a variety of process and product measures, and to choose children with a breadth of dissimilar needs so as to cover as wide a spectrum of application and development profiles as possible. This decision, in turn, constrained and defined the role of the researcher: she would be both observer and supporter; materials developer and progress chaser. The outcomes we hoped for could be divided into three areas: evaluation, product generation and testing, and engineering feedback:

- *Evaluating* involved testing the effectiveness of the chair in a broad range of settings, with the evaluator acting as participant observer.
- *Product generation* covered the project's aim of creating support materials, with evaluators working as part of the support and training team.
- *Engineering feedback* involved helping shape the evolving design of the Smart Wheelchair, by providing timely information to the engineers during the project.

2.3 Evaluation Aims and Approaches

2.3.1 Questions

Assessing the effectiveness of the chair turned on finding answers to the following questions:

- Is the Smart Wheelchair *safe*?
  In part, this is our equivalent of a baseline medical issue, namely 'does the treatment at least not harm the patient?'. Here, analogous questions might be 'does the Smart Wheelchair close off avenues of development?', 'do children become unhealthily dependent on the Smart Wheelchair', and 'can they be harmed, either accidentally or by long-term exposure, by the Chair?'.

  There are other safety aspects though. The Smart Wheelchair will work in crowded environments. Will anyone or anything else suffer?
- Does the Smart Wheelchair help motivate passive children?
  And, associated with this, 'can this motivation be harnessed to other developmental goals', in particular, social development, communication, and mobility? On the latter -
- Is the Smart Wheelchair effective as an augmentative tool for children who will never drive a conventional powered chair, and are there groups for whom this approach is unhelpful?
- Can the Smart Wheelchair be used as a transitional training tool for children who might eventually master conventional powered chairs?
- What are the preconditions for success?
  Issues include: what training is needed? what adaptations are required? how much support is needed by staff, and when? and what are the best environments in which the child can exploit what the Smart Wheelchair offers?
- What are the costs, and implications for provision?
  Including indications of: the relative costs of chair; training; adaptation; and support.

2.3.2 Evaluation methodology

For effective school based evaluation, there must be a contract between researchers and participants on what will be delivered, by whom, and when. Clearly, the researcher needs to be sure that access will be possible, that interventions will be jointly agreed and carried out, and records will be made. The other side of the coin is that the research has to be attractive to the participants. It must bring some new opportunities to the school and their children which are perceived as immediately useful by teachers, therapists, and parents. For this reason, it was tactically appropriate to work with children with a variety of needs: Scottish Special School populations are very inhomogeneous. More than this, though: school based research needs support. Especially so for technological research, where training (and retraining), fault-finding and fixing, and loan of equipment and backup must all be in place if the existing curriculum is to be distorted to fit the new equipment and practices. Where the experiments are long term (in our case, over a period of years), these services become crucial. Finally, where the issues are as broad-based as those in our study, the ways in which data are collected must not place undue burdens on the school staff.

This last requirement dictates the quality and extent of data which can be collected. Our approach was to make as much use as possible of existing records, looking only to add new data when either one particular school's record-keeping did not cover the same ground as the records kept by the other schools, *or* when we needed specific information not kept by any school. School records often do not yield such precise pictures as would be revealed by, say, psychometric batteries (when these can be applied at all). They are, however, a shared resource, easily understood by all members of the team, and they are not atomistic or professionally secular.

The project team and the schools collected evidence of child progress in three forms. Pre-study profiles of relevant aspects of the child were prepared, and compared with post-study profiles to the same format. Long term process records were prepared which related major stages to the environment and activities of the time. Finally, for a selection of the children where a major focus was on interaction and assertiveness, micro studies were made comparing pre-intervention and post-intervention behaviours over short periods.

2.3.2.1 Pre/post study profile comparisons

Objective standardised testing of children with profound or multiple disabilities is extremely difficult, and comparative studies are therefore problematic. This is especially so where the target group diverges widely in age, stage and ability, as with the case studies here. In the main, therefore, schools did not (and could not) test children in ways which would have helped the project team to present comparative objective evidence.

This situation reflects a fundamental reality, which is that assessment of children with the kinds of complex special needs seen in this project is unlikely to be achievable outside meaningful settings and tasks, and can best be achieved through functional observation techniques. One of the aims of the project was to promote Smart Wheelchair based observational techniques to help in such functional assessment. We therefore expected that initial profile accuracy and coverage would improve as observations progressed: this proved to be the case. It follows that the apparently sharp distinctions we are making between profiling and intervention are, in reality, quite blurred: intervention supported assessment, and refined our views of the children.

The pre-study profile served three purposes: it defined the baseline situation of the child; helped in the assessment process which decided on seating and controls, and helped staff and the project team define the developmental goals for that child.

Profiles took a broad view of the child, recording the following information:

- Physical state and medical history
- Personality and cognitive state
- Vision
- Hearing
- Communication
- Educational stage
- Social abilities
- Mobility

Initial video records taken in home and school also contributed to the profile creation exercise.

The profile record functioned as our triangulation instrument. Where evidence from multiple contributors appeared to bear on a significant item in the profile, they were grouped and compared, and any discrepancies identified.

Finally, the profile acted as the focus for generating and negotiating aims for each child: the aims were related to profile features of particular concern, and were the starting point for curriculum development.

The profile template is shown in **Annex 1**.

2.3.2.2 Long-term process measures

Long-term processes were recorded using a combination of direct observation by the evaluator, diary keeping by school/parental teams, and ex-post-facto examination of video sessions.

The format for the diaries used by schools teams is shown in **Annex 2**.

Long-term process data are reported in two more more compact forms: as case studies, and as process charts. The process chart brings to a single sheet a distillation of the child's experiences and performance over the project period. We discuss the interpretation of these charts further in section 4, where the case studies are also presented.

2.3.2.3 Short-term process measures

Behavioural studies were made by transcribing pre- and post- study video sessions into computer readable form, and then analysing the resulting sequences for evidence of significant shifts in patterns of specific behaviours. The tools used for transcription, analysis, and plotting of these data are described in **Annex 3**. The ways in which they were used in this study is discussed further in section 4, where the results are presented as part of their respective case studies.

2.4 Product Goals and Product Testing

In the current project-based funding environment, a programme such as that for the Smart Wheelchair depends on finding overlapping incremental funding from diverse sources. Earlier projects must provide the foundation on which later ones can build. It is important, therefore, to be aware at the start of a project, what the likely goals will be of the one which will follow it, in order to facilitate them.

We were clear that the Smart Wheelchair would need to move to production, and that provision of service and training would be part of that next phase. It was therefore important to identify basic products which would help at that stage, and produce them during the current work.

We expected to need:

- Hardware and Software Design Support
  The technical team would need good liaison with project schools: we planned that the agent would be the evaluator, and that her comments would guide the design process.
- User Handbooks
  The Smart Wheelchair would need a number of support documents for users. It would be the responsibility of the evaluation team to write and field test these.
- Guidance notes for assessment and curricular support
  Novel systems cannot be introduced into school or therapy without suggestions for how they may be used. The evaluation team were to write a starter set of these materials, and improve them on the basis of school comments and innovatory uses of the chair.
- Training packages and associated support materials
  Several levels of training were envisaged, from introduction to detailed in-service courses. These each needed training packs.
- Dissemination
  The evaluators, with other team members, would disseminate the progress of the project through papers, conferences and seminars, and short and long courses.

2.5 Evaluating the Evaluation

Formative evaluation has weaknesses, only some of which can be addressed by techniques such as data triangulation. We comment later on the strengths and weaknesses of formative evaluation and action research as they appear in cross disciplinary studies such as this which also cross both governmental departmental funding boundaries, and draw on non-governmental funds.

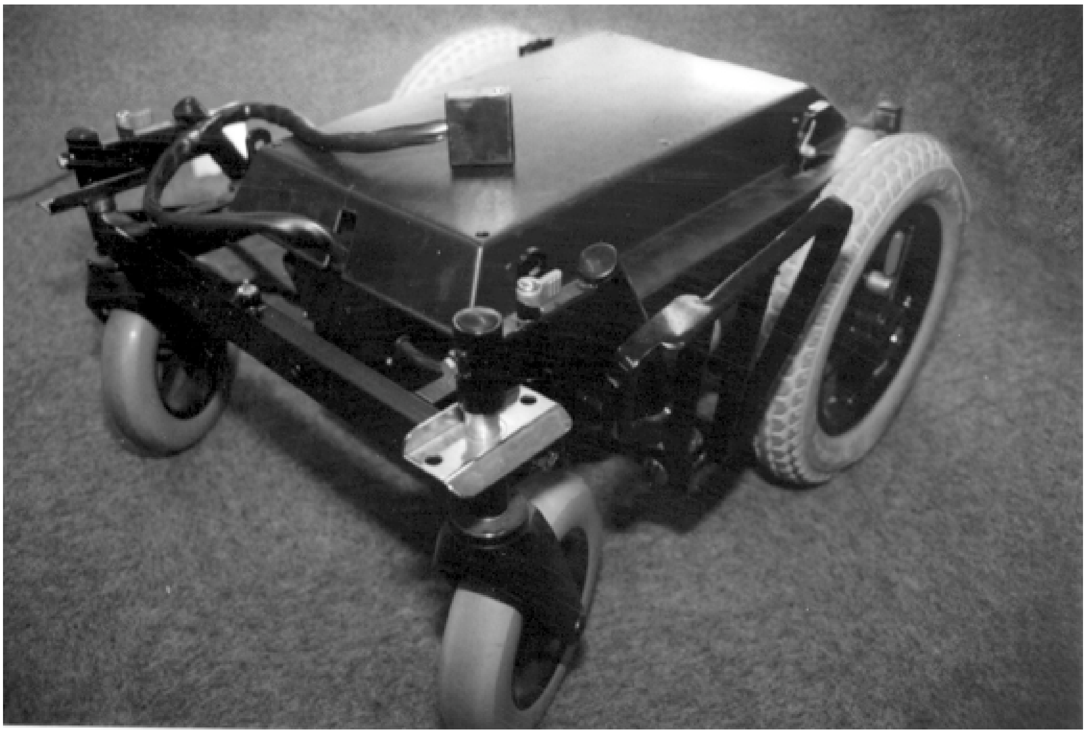
3. Setting the Scene

As we noted above, faced with the choice of deploying all the resources available on one subset of potential users (and thus enabling finely controlled studies to be set up), or broadening the investigation to cover as wide a range of applications as possible (and settling for less statistically satisfying, more impressionistic studies), the team opted for breadth. The strategic reasoning was straightforward: there was unlikely to be a second opportunity to build and deploy such a large number of wheelchairs again unless their value could be demonstrated. Focussing on a limited area of application would not generate awareness in policy-makers and professionals of the other uses of the wheelchair. This in turn would make it difficult either to establish the possible demand for commercial products and services, or to determine what those products and services should look like.

Three schools were involved, and all used a new version of the Smart Wheelchair. Our test-pilots included speaking and non-speaking children; those with severe physical problems, and those who were marginally too poor at controlling a conventional powered wheelchair to be prescribed one; children with demonstrably good perceptual and cognitive abilities, and those about whom there were doubts; males and females; assertive and passive children; and a range of ages from young adult down to a three year old nursery-goer.

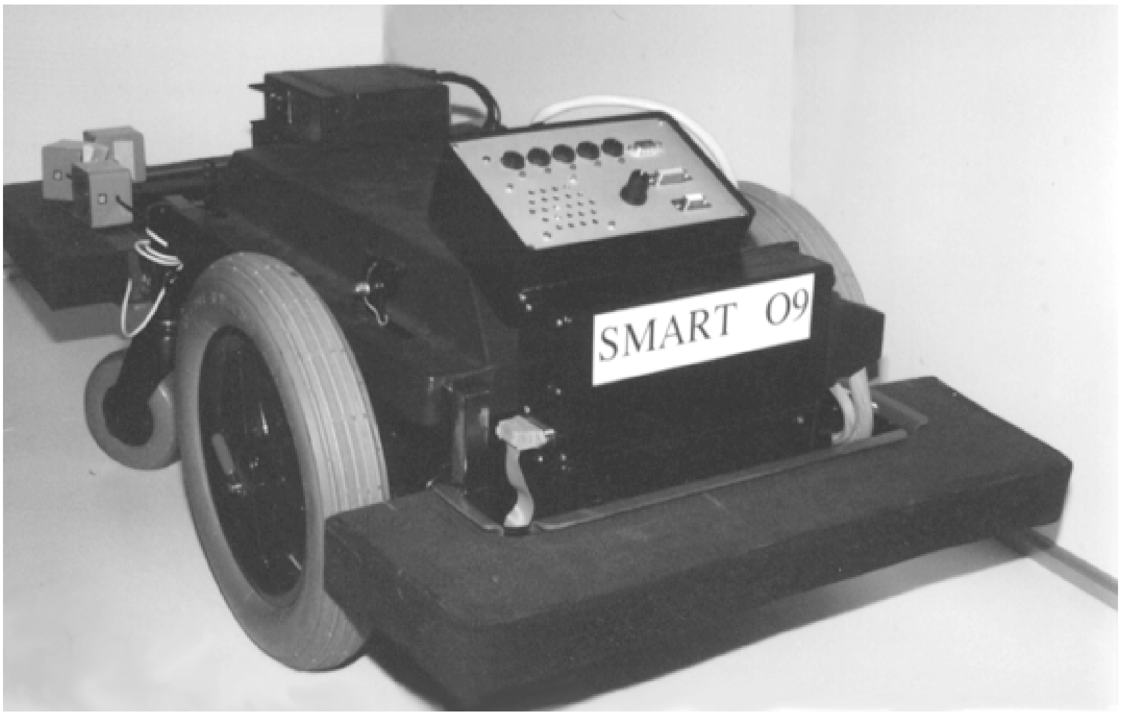
3.1 The New Smart Wheelchair

The Smart Wheelchair design used in the project is based on a Newton Products standard chassis, with CALL's electronic modules acting as the Smart link between the child's control, the chair sensor systems, the observer and the motor driver.



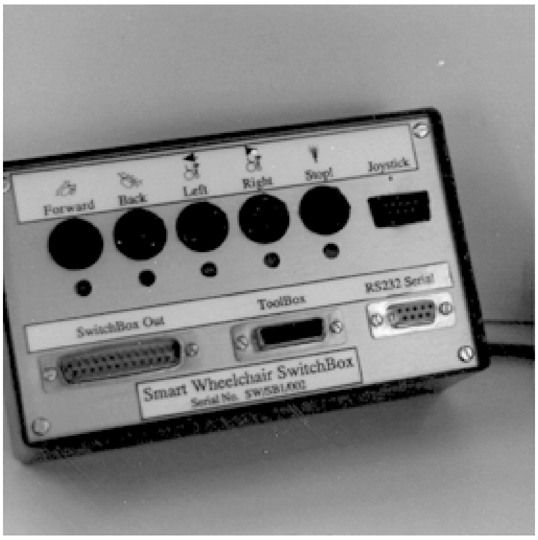
Commercial chassis, before Smart components are added

The sensors most used in school trials were bumpers: these are mounted front and rear, as shown in the picture below (which also shows the Switch Box interface unit).



Chassis with front and rear collision sensors and electronics added

Most user controls are connected via an interface (the Switch Box) which will allow connection of single or multiple switches, switched joysticks, and serial links. The latter enables riders to control the chair via suitable communication aids, or external computers, and also allows the Smart Chair to relay messages via these systems to the user. Finally, a socket is provided for the simple setup unit described below.



Smart Wheelchair Switch Box - the main interface to user controls

Later Switch Boxes also house the speech synthesiser, which is the Observer's normal mode of communication with the rider. The whole unit is mounted on the rear of the chair.

Simple system setup is achieved in two ways. Tool choices are made by temporarily connecting a small unit to the chair: speeds are adjusted on the controller. Once tools have been selected, the unit can be removed, and the chair will store the configuration.

Smart Wheelchair Toolbox

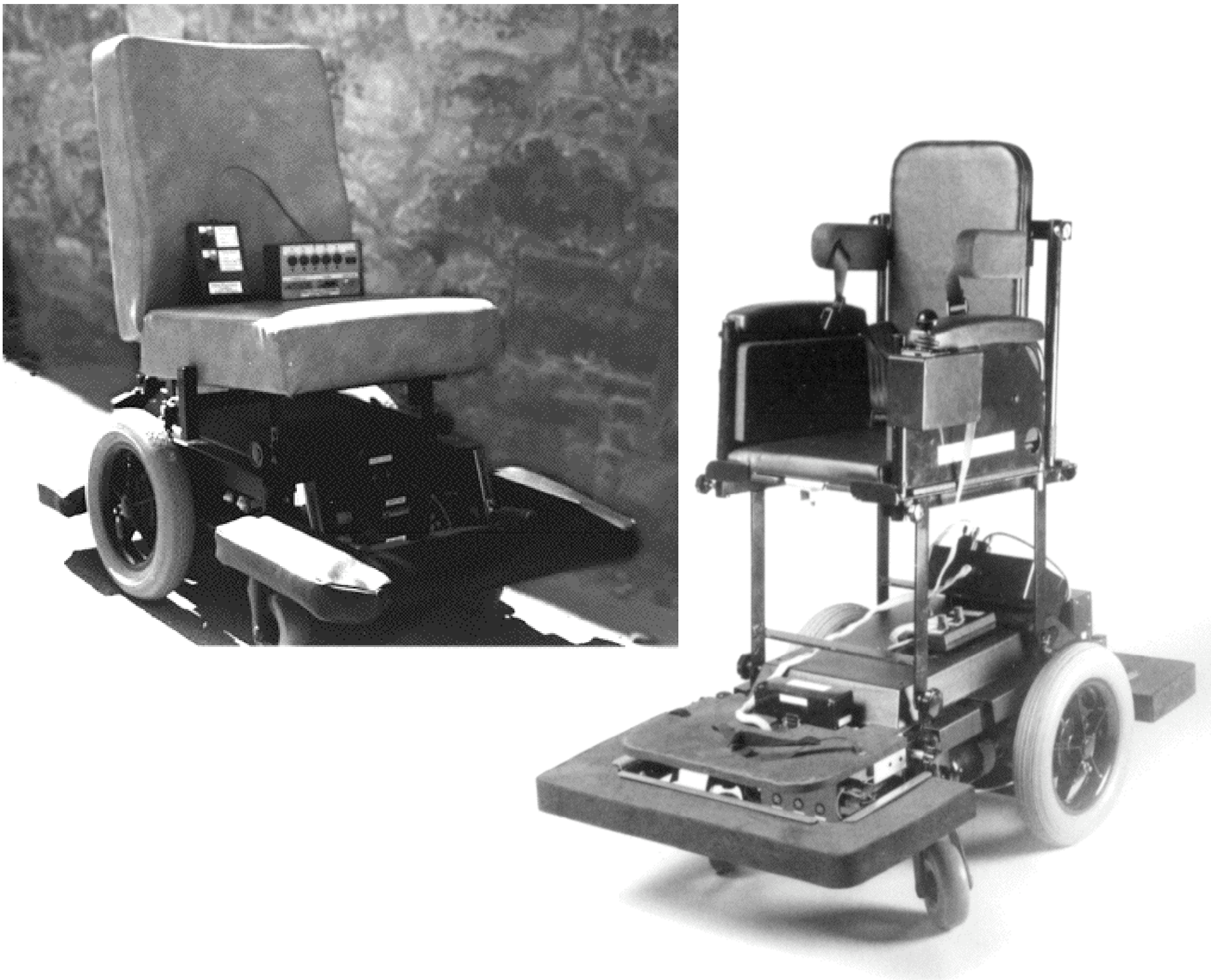
The simple setup unit allows teachers and therapists to choose Motion tools, which dictate what happens when a control is operated; and Bump tools, which determine how the chair reacts to collisions.

‘Timed’ motion moves the chair a specified distance for a control selection; ‘Latched’ will start the chair moving on one selection, and it will remain in motion until the next. ‘Momentary’ moves the chair while the switch is depressed, and stops it when released. The latter is the most difficult to control, needing strength, timing, and ability to concentrate on both switch targeting and mobility tasks. The easiest (and the one normally chosen to start work) is ‘Timed’.

There are three collision tools. The first is ‘Bump and Stop’: after a collision, the chair allows no further moves in that direction, but the user can drive in any other direction (provided they have enough degrees of control). The second tool is ‘Bump and Back Off’ - the chair moving back from the obstacle; and the last is ‘Bump and Turn’. This tool moves the chair away from the obstacle, and turns slightly, giving (as with the prototype) primitive steering.

To this combination of chassis and electronics can be added a wide variety of controls and seats.

Seating systems are mounted on subassemblies which connect to the chair using two hand screws. An example based on a child’s car seat was shown in section 1. Overleaf are two others. One chair has the manufacturer’s standard seat, while the other carries a wood and foam small seat on a metal subframe, with non-standard footrests.



Two types of seating system. On the left, using the manufacturer's seat; on the right, an individually tailored system

Controls can be any of the hundreds of specialised switches, switched and gated joysticks, and analogue joysticks on the market for augmentative communication and writing systems. Control can also be via scanning systems, including those in communication aids, and by external computer.

Each chair chassis in the project was first constructed by CALL and Bioengineering to the basic chassis and controller standard, and then tailored to the seating and control needs of each individual child as the assessment process unfolded. In a very few cases, where specialised seating was not an issue and where chair were used for short therapeutic sessions, a single, conventional seat was used, with short-term adjustments being made by therapists for each session. In the main, though, the model was of individual seating and control systems being provided, and, wherever possible, a dedicated chair for each child.

3.2 Collaborating Schools and Children

3.2.1 The children

After seeing presentations describing the prototype, and hearing an outline of our proposals for the current project, the schools concerned were asked to suggest children who might be involved. Of the 33 put forward, the schools and the project team identified an initial group of 9, the choice being guided by the project's aims for a broad spread of special need.

(In addition to this original group, physiotherapists in one school identified a small sub-group of potentially transitional riders, who they considered might benefit from Smart Wheelchair based assessment and practice en route to more conventional powered chairs.)

The main group were aged from 3.5 to 15 years old when the project started. Nine children were male, and one female. All suffered from cerebral palsy and only one was at all ambulatory. All had too poor hand control to operate a conventional powered wheelchair controller. In seven cases, motor coordination was so poor that switch operation was also difficult. Most were described as passive or poorly motivated. Only two had any speech, and only one used any augmentative communication aid.

In two cases, there was some doubt about the child's vision. Where communication was particularly poor or passivity great, there was often doubt about cognitive abilities, especially memory, attention, and problem solving.

In one main study case, the child had been previously assessed, and rejected for, a powered wheelchair.

The table overleaf summarises the children's' profile data as it was known at the outset of the project. Note that an empty cell does not necessarily indicate that the child has no such problem, but possibly that no information was available. (We accepted less than complete profiles, since one of the aims of the project was to improve assessment accuracy over time through functional observation).

3.2.2 Their support: schools, therapists, and parents

Action research is a well ingrained tradition in the CALL Centre. Since its creation in the early eighties, CALL teams have often worked in schools on commonly negotiated goals. However, the evaluation questions in section 2 called for more than just breadth of children's needs through school-based action research: they required breadth of observation across schools. To identify environmental factors, there needed to be environmental variety. The team were lucky enough to recruit three Edinburgh Special Schools, each with a distinctive style, each having children who might benefit from the project, and from whom we could learn.

Westerlea is a Scottish Council for Spastics school with pre-school, primary and secondary schools on the same site (although the name belies the increasingly diverse range of children the school handles); Oaklands is a local authority school, again serving an intake of children with a complex mix of more difficult special needs, and again catering for multiply handicapped children of all ages. Some of Oakland's children have only slight physical but severe mental disabilities. Finally, Graysmill is another local authority funded school, which to date has taught more able children with mainly physical difficulties (although here, also, the mix is changing). Two of the schools operate traditional school calenders, whilst one operates 52 weeks a year.

The process of identifying the children for the project also identified the school team for that child. We aimed for a balance of teaching and therapy staff, and where possible included one or more of the parents. Each child had a named key worker, who would be that child's primary contact with the evaluator and the technical support group. Finally, each school also appointed a managerial contact.

Name	Adam	Alan	Cameron	David	Graeme	Jack	Ross	Sara	Stephen	William
Age on Entry	12	15	3.5	8.5	9	6	13	7.5	11	6.5
Condition	Cerebral Palsy - Rt Hemiplegia	Cerebral Palsy - spastic quadriplegia	Cerebral Palsy - spastic quadriplegia	Cerebral Palsy - Ataxia	Cerebral Palsy	Cerebral Palsy - spastic quadriplegia	Cerebral Palsy - spastic quadriplegia	Cerebral Palsy - spastic quadriplegia	Athetoid Cerebral Palsy	Dystonic quadriplegia
Psychological and personality issues										
Passive			●	●	●			●		●
Easily distracted	●	●	●	●	●	●	●	●	●	
Memory difficulties	●		●	●	●			●	●	
Poor concentration	●	●		●	●	●	●	●	●	
Opting out behaviour	●					●	●		●	●
No object permanence	●				●					
Vision										
Poor vision / visual ability unknown	●				●					
Poor object fixation					●				●	
Poor visual tracking					●					
Hearing										
Unable to locate sounds					●					
Unable to track sounds					●					
Expressive communication										
No, or unintelligible speech	●	●		●	●		●	●	●	●
Unable to make/maintain eye contact					●			●	●	
Unable to comm. choices or poor yes/no	●	●			●					
No initiation					●					
Poor turn-taking	●				●					
No peer interaction	●	●	●	●	●			●	●	●
Poor/no use of AAC	●	●		●	●		●	●	●	
Receptive communication										
Poor or no understanding of speech	●				●					
Poor or no understanding of symbols	●	●			●		●	●	●	
Poor listening skills	●	●	●	●	●	●	●			
Educational issues										
No concept of causality					●					
No evidence of problem solving abilities					●			●	●	
No colour discrimination	●	●	●	●	●		●	●	●	
No understanding of number	●	●	●	●	●	●	●	●	●	
Physical state										
Poor/no head control					●			●		●
Poor/no independent upper limb control		●	●		●			●	●	●
Poor/no independent lower limb control		●	●	●	●		●	●	●	●
Fixed skeletal deformities	●	●								
Frequently unwell	●				●					●
Movements affected by reflex activity			●			●		●	●	●
No independent sitting		●	●	●	●			●	●	●
Poor / no hand control		●	●		●	●		●	●	●
No independent mobility	●	●	●	●	●	●		●	●	●
Seating difficulties		●						●		

3.3 The Evaluation and Design Team

Directly employed on the evaluation project were:

- a physiotherapist (full time) who undertook the bulk of the formative evaluation
- an educational technologist with expertise in augmentative communication (.2 full-time-equivalent), responsible for project direction and management
- secretarial support.

Directly employed on the sister Smart Wheelchair technical project were

- an electronic designer (full time), and
- an electronic designer / programmer (.5 full-time-equivalent).

The wheelchair design project also benefited from substantial contributions to assessment made by Bioengineers in Princess Margaret Rose Hospital, undertaken in addition to their Chair, seating system, and control construction work.

3.4 Process

3.4.1 Smart Wheelchair acquisition:

Assessment, and the definition of individual aims and goals

Before selection of the children, each of the school/parental teams was briefed on the capabilities of the Smart Wheelchair and provided with case studies and videos drawn from our work with the Smart Wheelchair prototype. The object was to promote informed advice during the initial selection and profiling exercise, and to generate comments which could help the assessment process.

The pre-profile video sequences were taken in home and school. We took care to find situations and sequences which the school/home team agreed were typical of the child, and which covered mobility, communication, and control aspects.

These baseline videos were then supplemented by completion of the Pre-study profile. Where objective records were available, we used those: where they were not, we sought opinion and studied the video record and the child to form a view. In either case, we triangulated the evidence. Where there was a disagreement, we reduced our confidence in the evidence, and noted this also. (As we said in section 2, objective standardised testing of children with profound or multiple disabilities is extremely difficult, and rarely attempted. Comparative objective evidence was therefore equally hard to come by.)

Some information turned out to be very difficult to get. Although we were urged by our advisory committee medical member to use the medical records of the children, we were not able (despite repeated attempts) to get access to all of them. This was particularly disappointing to the team, especially since original encouragement to use such material had come from the profession itself.

During the process of profile gathering, whilst the school/home team was focussed on the child's needs, we collectively decided on the aims for that child. Again, where the aims were already articulated (as where a Record of Need was in place, or where the school had an ongoing programme of work into which the wheelchair could fit) we incorporated them. Where they were not well defined, we helped the group to set them up. It was to be expected that some teachers and therapists needed such help and guidance, since the possibilities offered by the Smart Wheelchair are novel. Some of the early aims were either wildly ambitious, or extremely cautious and traditional, and these tended to be refined during the early stages of the project.

Tailoring and adaptation

During this period, the technical team were reviewing seating and control issues. Often, a child was already using specialised seating, and may have been using some form of switch or other control (to operate toys or computer programs). Where possible, the technical team used these as a foundation on which to build during the assessment. However, it was usually the case that seating systems had to be built from scratch to meet the new dynamic environment, and that controls needed adaptation.

The assessment and tailoring processes interwove. It was especially noticeable how many refinements were needed in the first few weeks after initial delivery, when particularly rapid changes in the child's abilities took place. It is not clear if this phenomenon is the result of better motivation revealing latent skills; better seating environment enabling better control; or more opportunities for close observation producing better assessment.

3.4.2 Introduction and initial training

While the chair was being built and tailored, staff and parents underwent training sessions on the Smart Wheelchair, using one of the backup chairs for hands-on work. These included technical and safety features, described how the chair would be introduced, and related the aims for the child to what would be attempted during the project.

These sessions also outlined the data gathering work to be done, and introduced the observation diaries.

Children were introduced to the Smart Wheelchair in stages, extended over time in cases where there was some doubt about the child's fearfulness or opposition to new experiences. Typically, the chair was driven in the child's field of view by another person who the child trusted. Then, when it was judged that the child was confident that no harm befell its rider, she or he was given a ride on the lap of their key worker, but with control still in the key worker's hands. Then the child was allowed to try the control (as best they could, given that the chair was being ridden by two people). Finally, the child was placed in their own seat, alone, and went solo. A certificate for Going Solo marked this achievement.

In a useful variation on this procedure, we have also used the technique of co-driving. Here the child demands that an ambulant slave who holds the control drives in the direction the child wants to go. The feel of the chair can be got before having to deal with controls.

3.4.3 Intervention and observation

After the initial sessions, the programme of work varied between children: the case studies in section 4 outline their progress. During their programme, both school and CALL teams kept records of achievements and important incidents. Where significant events could be predicted or controlled (such as the introduction of a new tool, or a change to controls, or a first outdoor trip), a video record was made. Video records were also taken at regular intervals, and used with the technical and school teams as part of the continuous assessment process. Again, the results are outlined in section 4.

4. Case Study Outcomes

4.1 Interpreting the Results

4.1.1 Case study data

In this section, we present case histories of children in all three schools, including short summaries of a number of children in a small-scale programme using the Smart Wheelchair for transitional training and assessment purposes only.

Each of the main studies follows a similar pattern: pre-profile of the child and environment, together with a description of the aims for that child; a description of the chair adaptations resulting from the initial assessment; a brief history of the intervention; and a summary of changes. The summaries are supported by a long-term process chart, and (in cases where detailed analysis of interactions was needed) a short-term interaction chart. Both of these are described below.

We have grouped the children's case studies into four. In the first, we highlight transitional training for conventional powered mobility - children who might use the Smart Wheelchair as a training aid prior to being assessed for a normal electrical wheelchair. The second group emphasises training for augmented powered mobility, concentrating on aspects which are important when the child will never control conventional chairs, and will always be a Smart Wheelchair user. A third group focusses on use of the chair in reducing passivity, encouraging socialisation and interaction, and promoting exploration and play, while the final section describes cases who are combining mobility and communication aids.

This grouping of results is for expository purposes: schools' staffs' aims and interventions for the children in each group overlap considerably. In some cases, it was not possible at the outset to determine if a child is a transitional or permanent Smart Wheelchair user, and in the timescale of the project it has not been possible to resolve the issue for some children. Or to take another example, children in all groups will provide evidence on assertiveness and skills transfer.

In section 2 we outlined the observation and recording methods we used, including pre- and post-study profiles; direct observation; diary and other school records; video records and encodings. For the case studies which follow, we have condensed this data in a number of ways.

- Only pertinent features of children's profiles are included in the case studies.
- Long-term intervention and observation data are presented in two forms: as a narrative, and in a long-term process chart.
- In the narrative, we highlight pre- and post- profile differences (rather than presenting full profiles).
- Short-term process data derived from video records (used particularly where we are concentrating on interaction and assertiveness) are shown as interaction graphs.

Full profile, observation records, videos, and encodings are retained at CALL.

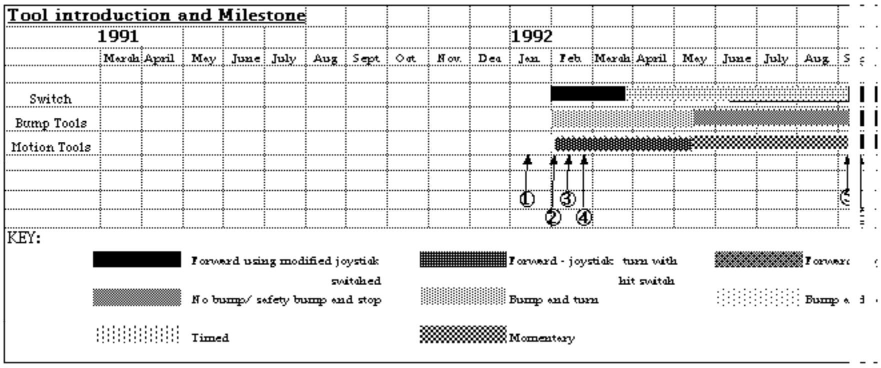
The two graphical forms contain a great deal of information. Before turning to the case studies themselves, we describe these in more detail.

4.1.2 Interpreting the long term process chart

These charts map the major project stages for each child, setting progress against environmental influences.

Records typically extend over several months to years: exactly when each child began work depended on their place in the queue for wheelchairs (which were all built during the project period), the post assessment individualisation of chair controls and seating, and the the preparatory work needed for staff and parents.

The lower section of the chart shows progress with the chair. The horizontal bars show which tools were in use: which control, what bump tools, and which kinds of motion were allowed. Progress can be revealed in a number ways. For children who are using the chair as a training aid, we would hope to see a continued reduction in chair bump tools, increased numbers of switches, reduction in gating of joysticks, and a move away from timed control to momentary. However, for children for whom the Smart aspects of the wheelchair are necessary long-term aids, or where the teacher is aiming to promote non-mobility developments, a different interpretation is needed. In these cases, the issue is not necessarily how fast the child progresses through the chair's repertoire of tools, but what is achieved at each stage. The lower part of the chart therefore also identifies specific events which signify important changes in performance: these events are elaborated in the key list accompanying each chart.

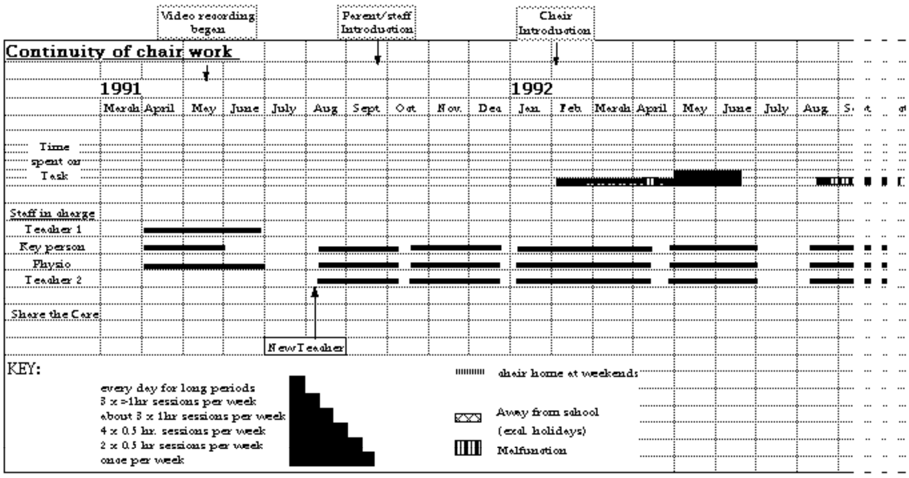


The lower part of the long-term performance chart serves as a shorthand for the overall process. However, it also contributes to the formal record of achievement, and the contents should be viewed as part of the objective measures. Taking mobility aspects alone: test batteries of driving skills normally try to emulate a progression of increasingly difficult day to day tasks such as these -

Simple moves	being able to make the chair move
Stops	being able to stop the chair appropriately
Straight line	being able to keep the chair moving in a straight line
Pointing	using the chair to point to an object
Twin curve	steering the chair around an S-shaped curve
Left sharp turn	90˚ turn to the left
Right sharp turn	90˚ turn to the right
Multiple sharp turns	sharp turns to the right and left consecutively
Reverse	being able to reverse the wheelchair safely
Three point turn	changing the direction of the chair in a confined space by reversing and turning

Instead of abstracting the task from the setting, a functional assessment will try to structure the environment to offer opportunities for observing the skill in practical use. A child's progress from one control or tool to another implies mastery of the skills needed for the previous tool, and the sequence of such observations forms an objective record of improved functional performance. We consider such measures to be important not only as a part of the project methodology, but also as an indication of techniques for using the Smart Wheelchair in continuous assessment of performance. Note that such measures are highly contextually bound: this is a characteristic of functional measures which makes it crucial to record both action and context if observations are to be understood.

The upper part of the chart serves to relate child progress to important contextual features. These include the length of time children were able to work in the chair; the staff involved at the time; and the timetable of assessment, chair build and tailoring, and introduction to the child.



The histogram of 'Time-on-task' is not to scale, and should be interpreted with care. A child showing a record in the upper levels ('every day for long periods') is probably using his chair as his main seating and has it always available for exploration. The child will have a genuine sense of personal ownership, and much opportunity to practice. In contrast, the child in the lowest band is only recorded as using the chair *once per week*, with all that implies for their opportunities for progress. The ratio of usage between upper and lower bands can be forty or fifty to one.

To identify what problems might be affecting access, the chart records absence due to illness, and chair mechanical, electrical or software failures.

The 'staff involvement' bar charts (below the time on task histogram) help indicate effects of staff changes.

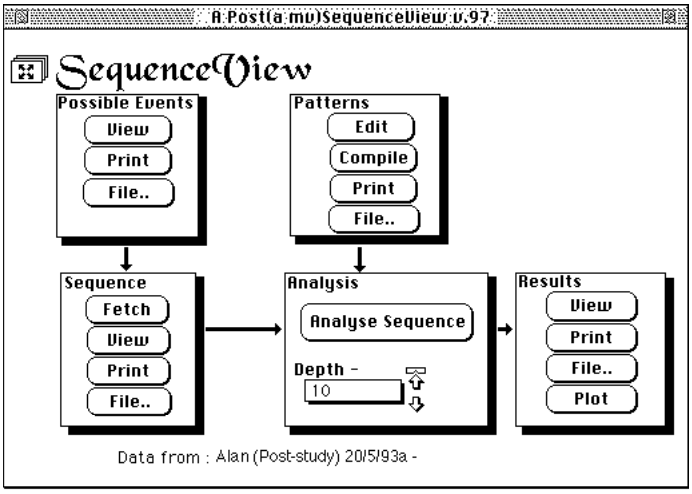
In a complex programme (typical of new technology-based curriculum development), initial training and ongoing support is vital. We record which staff professions are involved in the project: usually teacher or therapist, perhaps nursery nurse or classroom assistant. We note who the key person is; and we record when they are present during the intervention.

In three cases for which one of the major concerns was interaction and communication, we chose to focus on assertiveness, responsiveness, and persistence of effort through analysis of video sequences. We discuss the coding and interpretation of these next.

4.1.3 Pre- and post- study short term behavioural analysis

Interpreting Sequences

For those children whose development aims particularly stress either improved communication effectiveness, or reduction in passivity, we compared pre- and post-study short-term behaviours by coding and analysing fragments of the video record using three computer packages developed at the CALL Centre, called *SequenceView*. In this section we outline how the analysis is carried out, and how to interpret the results. (For more details of *SequenceView,* see **Annex 3**).



SequenceView is a general purpose tool, and is neither tied to the events we chose to describe children's behaviour in Smart Wheelchair, nor restricted to searching for particular patterns within sequences of those events. We have to define both.

SequenceView treats its search for specific behaviours as a similar task to parsing sentences. In this analogy, the raw events are similar to words in the language; the sequence is a noisy collection of simultaneous conversations; and the behavioural fragments we are searching for are like sentences within the sequence.

Of course, *SequenceView* has no in-built grammar of behaviour. The fragments we will have it look for are defined by us - they form a model of our hypothesis of what behaviours we believe might be found. *SequenceView* is different from most linguistic parsers, in that it can handle concurrent, overlapping, and embedded behaviours (whereas most views of natural language treat any given sentence as a singular entity, with (hopefully) one meaning. So our definitions might include temporal relationships between fragments.

In the Smart Wheelchair study, we have restricted ourselves to simple models, concentrating on interactions. (However, the data we have collected contains much more detail, and we hope to encourage further study of it.)

Events

We begin by defining the Events, telling *SequenceView* what legitimate codes we have used for our classroom measures. Choosing an eventset for behavioural observation and analysis is tricky: too small a set of events will often result in building too much of the result into the observation (we say the event is ‘too high inference’). For instance, to include an event such as ‘Child bored’ is to claim that we can distinguish from his or her actions that boredom and not, say, tiredness or minor fit is the cause of such behaviour.

We have therefore chosen a low inference set of events. We split such things as ‘Child initiations’ into the act, and the means (so that we can later search for different modalities, such as initiations via communication aids versus by gesture). So that we can search for context-related activities, we also record physical location and surroundings, peer activity, and adult activity. Finally, we recognised that communicating partners could be non-human: in our eventset, the Wheelchair, communication aids, and computers can all initiate, and respond.

The set we used is as follows:

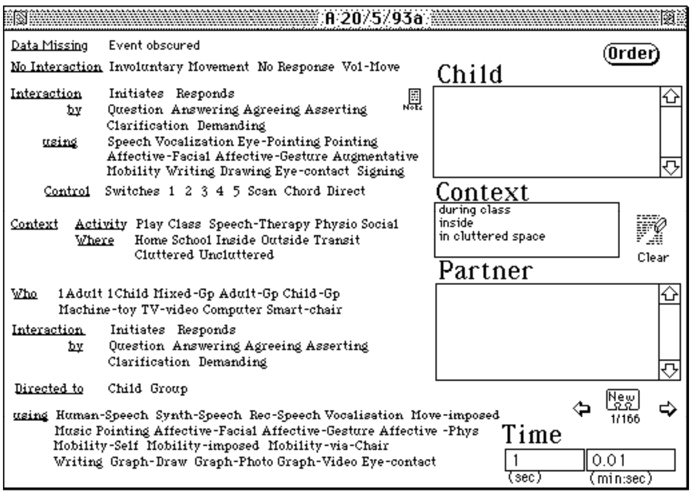
*,anything (inc nothing)	e28,at school	e58,by demanding
§,start of sequence	e29,inside	e59,directed to child
#,any event	e30,outside	e60,directed to group
e1,Child makes involuntary movement	e31,in transit	e61,using human speech
e2,Child makes no response	e32,in cluttered space	e62,using synthesised speech
e3,Child initiates interaction	e33,in un-cluttered space	e63,using recorded speech
e4,Child responds to interaction	e34,control 1 -switch	e64,using non - speech vocalisation
e5,by questioning / investigating	e35,control 4 -switch	e65,using music
e6,by answering	e36,control 3 -switch	e66,using pointing
e7,by agreeing	e37,control 2 -switch	e67,using affective - facial expression
e8,by asserting	e38,control 5 -switch	e68,using affective - gesture
e9,by seeking clarification	e39,control Scan	e69,using physical control of the child
e10,by demanding	e40,control Chord	e70,using mobility of communication pa
e11,using speech	e41,control Direct	e71,using enforced mobility of child
e12,using non - speech vocalisation	e42,1 adult	e72,using chair under partners control
e13,using eye-Pointing	e43,1 child	e73,using writing
e14,using other pointing	e44,mixed group	e74,using drawn graphics
e15,using affective - facial expression	e45,adult group	e75,using photographs
e16,using affective - gesture	e46,child group	e76,using video graphics / animation
e17,using augmentative system	e47,machine or toy	e77,using eye contact
e18,using mobility act	e48,TV /video / film	e78,Child makes voluntary movement
e19,using writing	e49,computer	e79,using signing
e20,using eye contact	e50,Smart Wheelchair	e80,using enforced movement of child
e21,using drawing	e51,initiates interaction	
e22,while playing	e52,responds to interaction	
e23,during class	e53,by questioning / investigating	
e24,during speech therapy	e54,by answering	
e25,during physiotherapy	e55,by agreeing	
e26,in social discourse	e56,by asserting	
e27,at home	e57,by seeking clarification	
	e58,by demanding	

Although our recording tool (a program called *SequenceView Transcriber*) allows us to code and view events in this verbose way, *SequenceView* is more terse, and just uses the e-codes, as follows:

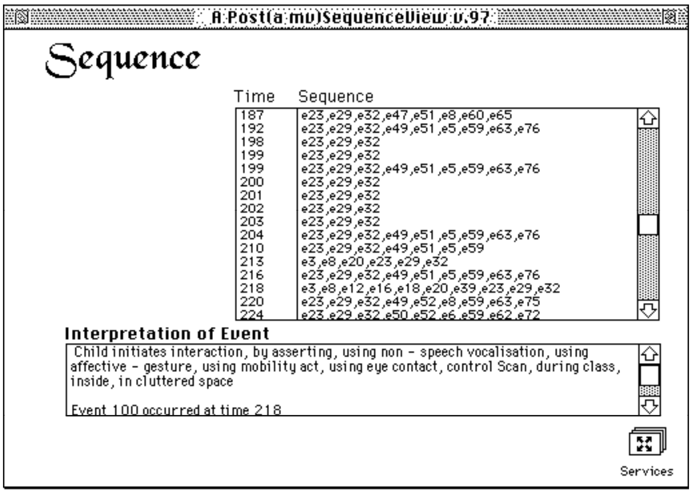
```
event("*")
event("§")
event("#")
event("e1")
event("e2")  ... to
event("e80")
```

Sequences

A Sequence consists of a series of groups of observations, together with the time they happened. Each group represents the situation at that instant. The *Transcriber* allows us to define a group by clicking on the sub-event actions, and to view the result as a more-or-less English description.



Here is a set of sample events (taken from the middle of the transcription of Alan's pre-study video):



In the ‘Interpretation of Events’ box, *SequenceView* has converted the e-codes at time 218 back to English for human browsing.

Most of the time, we will not be concerned with individual events, but in the patterns which can be drawn from them.

Patterns

In this study, we were primarily interested in the pattern of interactivity of child and either peers or mobility aid. Initiation is a useful indicant of assertiveness, curiosity, and general exploratory activity, and the pattern of occurrences help to reveal persistence in children's efforts toward mobility and communication. The responses which these initiations elicit indicate the degree to which the initiation is successful, and shows something of the communicative balance during the observed period. We therefore asked *SequenceView* to search for three kinds of initiation behaviours: child, other human, or machine, and the responses springing from them.

Child initiation and response are particularly simple , and expressed like this

```
name ("ChildInitiates",Seq("e3") )
name ("ChildResponds",Seq("e4") )
```

- note that we ignore modality here. Any initiation is deemed to be important - gesture, vocalisation, switch actuation, or speech.

Other partner initiation is a bit more complex. We insist that the act occurs in a particular set of contexts. For the human, the initiation must come from *e42,1 adult* or *e43,1 child* or *e44,mixed group* or *e45,adult group* or *e46,child group* -

```
name ("HumanInitiates" , within(anyOf( "e42", "e43","e44","e45","e46"),"e51"))
```

while machine initiation can come from *e47,machine or toy* or *e48,TV /video / film* or *e49,computer* or *e50,Smart Wheelchair*-

```
name ("MachineInitiates" , within(anyOf( "e47" , "e48","e49","e50" ) ,"e51"))
```

We insist that responses are directed to the child (and not to the group, say), by combining *e52,responds to interaction* with *e59,directed to child* thus

```
name ("ResponseToChild",within("e52","e59") )
```

We can now start to use some of these basic patterns to build more complex ones. A basic interaction between child and others consists of an initiation and a response

```
name ("ImmediateResponseToChild", Seq("ChildInitiates","ResponseToChild") )
```

However, there may be a delay. We accept that several events could take place before the initiation is acknowledged (but we restrict the number to 3, maximum, on the grounds that anything longer makes it hard to be sure that the response is actually to the initiation in question, and not to a later one). We use the symbol ".#." to mean 'anything at all can happen here'

```
name ("QuickResponseToChild",
Seq("ChildInitiates",anyof(seq(".#."),seq(".#.",".#."),seq(".#.",".#.",".#.")),"ResponseToChild"))
```

A similar pair of patterns are defined for the interaction which is started by someone (or something) other than the child.

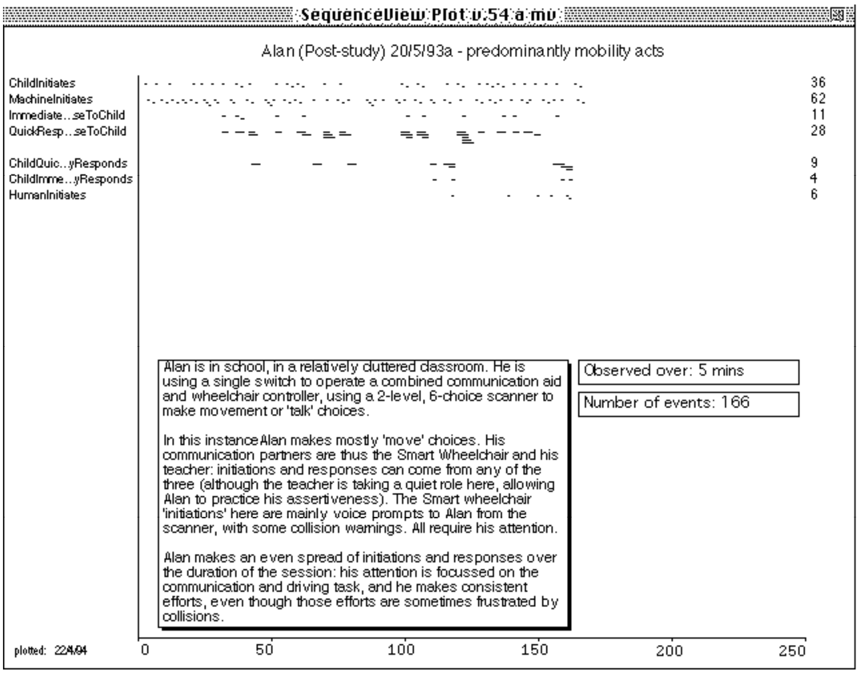
```
name ("ChildImmediatelyResponds",
Seq(anyOf("HumanInitiates","MachineInitiates"),"ChildResponds") )

name ("ChildQuicklyResponds",
Seq(anyOf("HumanInitiates","MachineInitiates"),anyof(seq(".#."),seq(".#.",".#."),seq(".#.",".#.",".#."))
,"ChildResponds"))
```

We also defined the 'any event at all' pattern used as a filler in the main patterns above

```
name(".#1.",anyof(e1,e2,e3,e4,e5,e6,e7,e8,e9,e10,e11,e12,e13,e14,e15,e16,e17,e18,e19,e20)

name(".#2.",anyof(e21,e22,e23,e24,e25,e26,e27,e28,e29,e30,e31,e32,e33,e34,e35,e36,e37,
e38,e39,e40)

name(".#3.",anyof(e50,e51,e52,e53,e54,e55,e56,e57,e58,e59,e60)

name(".#4.",anyof(e61,e62,e63,e64,e65,e66,e67,e68,e69,e70,e71,e72,e73,e74,e75,e76,e77,
e78,e79,e80)

name(".#.",anyof(".#1.",".#2.",".#3.",".#4."))
```

Interpreting the results

A typical observation might run from five minutes to half an hour, and contain several hundred groups of events. Finding patterns will reduce the number of data to more manageable proportions, but there can still be a hundred or more patterns. *SequenceView Plot*, the third package in the trio, prints a graphical representation of the patterns over time, showing them in relationship to each other. A pattern of short duration will show as a dot against the timeline: extended patterns appear as lines.



Some care must be taken when interpreting these graphs. Firstly, since the times and numbers of events vary, pattern numbers are not so important as ratios. For example, to appreciate the change in assertiveness of a child, you should compare, in pre- and post-study records, the ratio of numbers of initiations to the overall time. Or again, if you are interested in the change in interaction pattern, compare ratios of child to teacher initiations and responses.

Secondly, the plots reveal something of the persistence of the child. Similar numbers of patterns between two children may mean very different things if, in the one case, they are grouped together over a small period, than if they are extended evenly over time.

Moreover, the relationship between initiation and responses is important. The plot will reveal cases where children assert themselves without there being any obvious response, and who themselves do not respond to the overtures of others. These can be clearly distinguished from more balanced, turn-taking exercises.

Finally, the reader should note that these records are drawn from recordings taken in day-to-day settings. They are an example of *Functional Assessment*. As such, there are many contextual differences which will affect the day to day behaviours. Nonetheless, since we are interested in functional outcomes, and since real world settings define the motivational environment for children, we are satisfied that such measures are more useful for our purposes than laboratory tests.

4.2 Group 1: Transitional Training for Conventional Powered Mobility

4.2.1 Mobility Training Chair

Background

The main focus of the Smart Wheelchair project was to investigate effects of mobility on the development of very severely disabled children, and so chairs were supplied to individual children to ease access and encourage a sense of ownership. However, since the team also wished to investigate the use of the chair purely as a mobility training aid for more able children, a mini-project was set up in the Physiotherapy Department of one of our trial schools, using one shared chair.

Method

The intervention and evaluation procedure adopted for this chair was different from the other chairs. Since only mobility skills were under investigation, wide-coverage post-intervention profiles were not compiled. Instead, progress in driving was measured using driving tests and functional observation. Involvement of the research team members was minimal, partly because it was not necessary and partly to determine whether this form of use could be tackled without close support. In practical terms, this meant that the Physiotherapy Department were supplied with standard mini and medium Newton products seats, rather than individualised seating, and with a battery of control systems including various hit switches; switched joystick with gates; analogue joystick; and wheelchair tray.

The use of the chair was determined by the Physiotherapy Department staff. Intervention comprised regular driving lessons for a maximum period of six months. If the child was not making progress, lessons were stopped and another child in the school replaced the original subject. Records of performance were made through the department's established recording techniques and intervention consisted of three one hour sessions per week on average. The chair was not taken home or used outside these specified sessions. Results are presented here as mini case studies.

Kenneth

Kenneth is a 10 year old quadriplegic boy with an overlying right hemiplegia. There have always been doubts about the quality of Kenneth's functional vision and his visuo-perception. He is able to self-propel his manual wheelchair slowly over very short distances only. Despite repeated attempts, he was unable to master the control of a conventional powered wheelchair and so it was decided to use the Smart Wheelchair to teach Kenneth the skills required for powered mobility.

Kenneth began in September 1992 using a switched joystick (gated for 'forward' only) on a momentary setting, with the 'Bump and Turn' tool taking care of any collisions. He soon learned to start and stop appropriately and turning was introduced next. It was noted that Kenneth watched the walls as he was driving, shorelining (a skill used by the visually impaired either using limited near vision or a white stick to maintain a safe distance from the wall while following it as a navigation aid).

As Kenneth learned new driving skills, he needed less of the Smart Wheelchair's help. When turning was introduced by gating the joystick, his physiotherapist switched off 'Bump and Turn' in favour of 'Bump and Back Off'. By the time that Kenneth had control of all four directions in structured sessions, he had also demonstrated that he was able negotiate the school corridors and its obstacles, with few mistakes. He started practice in and around the classroom, still under supervision, but away from the timetabled 'driving lessons'.

The move from structured supervised driving lessons to free use in the classroom was an important step for Kenneth. His previous failure with a powered chair was possibly due not only to lack of physical control but also lack of confidence, partly caused by his visual impairment. Later, although he coped well in the familiar cluttered classroom, when driving in large, bare, unfamiliar places he appeared 'lost' and unsure because he could not see familiar landmarks to guide him. His visual impairment also affected him in very brightly lit situations when his control was noticeably poorer. Some simple environmental changes could improve cue-ing for Kenneth and children like him.

At this stage, his performance was tested on the driving skills stages outlined in 4.1.2 (these being driving skills agreed by other researchers and mobility assessors to be representative of increasingly difficult day to day tasks). For convenience, we reproduce them here:

Simple moves	being able to make the chair move other than randomly
Stops	being able to stop the chair appropriately
Straight line	being able to keep the chair moving in a straight line
Pointing	using the chair to point to an object
Twin curve	steering the chair around an S-shaped curve
Left sharp turn	90˚ turn to the left
Right sharp turn	90˚ turn to the right
Multiple sharp turns	sharp turns to the right and left consecutively
Reverse	being able to reverse the wheelchair safely
Three point turn	changing the direction of the chair in a confined space by reversing and turning.

Kenneth had mastered these skills to a degree which satisfied the staff in a three month period of time.

His Smart tools were disconnected and replaced with a standard joystick and wheelchair controller. Kenneth did exceptionally well, shouting and manoeuvring his chair around numerous obstacles confidently and safely.

Kenneth has been able to learn the skills required for conventional powered mobility in a graduated, safe manner, acquiring new skills and gaining confidence in his own time. The ultimate aim of this mini-project has now been achieved: Kenneth was referred to the local Vehicle Centre and now has a conventional powered wheelchair of his own.

Several factors contributed to Kenneth's success. The progressive training offered in a safe environment helped his motor skills and confidence and gave him a chance to develop strategies such as shore-lining to cope with his visual impairment. The training period was considerably shorter than David, the other child who progressed to use of a conventional chair and involved far fewer modifications to the control device, which suggests that the main skill areas which were influenced were understanding and personality-based.

Simon

Simon was 7 when he started with the chair in September 1992. He has dystonic cerebral palsy. He could weightbear, but was prone to falling as his dystonia suddenly affected his legs. He had started to use an Arrow Walker. He iwas eager and tried hard but is limited by his physical disabilities. He could speak a few words and appeared to understand simple requests and instructions. There was some doubt over Simon's perception although it was felt that his vision was probably unimpaired. The family were keen for him to participate as they wanted him to benefit from all school opportunities: they were not therefore interested solely in mobility.

The staff and parents hoped that use of the chair would not only develop mobility skills, but would also develop self confidence and esteem and encourage him to be more assertive.

Simon started with a momentary-controlled hit switch mounted on a tray with bump tools. Occasionally, other switches were added to test his ability to cope with two or three. After two weeks use he was felt to have mastered starting and stopping while going forward but was inconsistent when selecting the direction of turn. Labelling the switches with direction arrows made no difference and he would quite happily spin round on the spot for some minutes. After some time, with lots of practice, Simon's use of his three switches and his accuracy when lining up with doorways and objects gradually improved. However, he still loved to go round in circles. This seemed to be intentional play: on one occasion he ran backwards and forwards over a knobbly manhole cover outside the school, demonstrating fine turning accuracy in his efforts to play on this novel surface. After around six months he was able to manoeuvre through doorways with small sideways corrections and started to use the chair for functional mobility by moving to specific locations.

Although he did not develop control of a joystick, Simon is capable of driving the wheelchair using switches and has continued to use it functionally, during the times when it is available to him.

Brenda

Brenda was 13 years old when she started using the chair in September 1992. She could weightbear and walk only when held by a helper but could not walk with a rollator. She bottom shuffled and could maintain sitting balance when supervised. Her parents were keen that she should learn to drive a powered wheelchair. She was sociable but was described as having no sense of danger, a slow learner and having poor memory and concentration. Her speech was intelligible, and she could construct sentences and understood simple instructions. The staff hypothesised that her failure to learn control over conventional powered wheelchairs was due to cognitive disability and lack of interest (possibly linked to lack of understanding of why mobility was useful). They therefore hoped that the Smart Wheelchair would enable separation of powered mobility control functions; provide experience of functional mobility personally useful and motivating to her; and enable her to practice safely.

Brenda began with a gated, switched QED joystick under momentary control. She used the chair roughly two times per week. The gates were quickly removed after a few sessions use since she demonstrated that she could control all directions of motion. Her staff reported that she could perform very well and was capable of accurate driving, particularly in quiet, supervised sessions. However, she was so easily distracted when driving around the school corridors or in class that she was dangerous even with collision sensors. After several months use the staff reported no change in this behaviour and no improvement in her ability to follow instructions. Several different types of activities were used: free driving; games; use in classroom; but Brenda continued to exhibit a lack of interest and motivation to drive safely.

The staff concluded that although Brenda had sufficient physical and control skills to control a powered wheelchair effectively and safely, she had no appreciation of danger and little understanding of the usefulness of mobility. There are still unanswered questions. Using the chair only in the therapeutic sessions, she may not have come to understand that mobility could fulfil personal desires and wants by allowing her to move to (or away from) locations of interest (or disinterest). Alternatively, her cognitive difficulties may cause her to have few location-dependent desires or plans in the first place.

Brenda stopped using the chair at the end of 1992 and another child took over her timetabled sessions.

In Brenda's case, there may still be other approaches to try.

Promoting understanding and a desire for the power of independent mobility is one potential use of a Line Follower, following experiences reported by Paulsson. If a child is severely cognitively impaired then even if they are motivated to do so, using the chair with or without collision sensors may be too complex to understand. In order to move around the child must have an idea of where they wish to go, of the sequence of their actions and the chair's movements that will take them there, and the ability to correct this plan if unexpected events like obstacles are encountered. A line follower is much simpler to operate: the child just needs to know that if (s)he operates a very simple control, the destination will be reached (assuming that the line goes somewhere interesting and the child knows that). Choice of target can be introduced gradually.

It might also be used to motivate a child who seems unexcited by mobility, possibly again because of cognitive difficulties. One of the reasons for the child's lack of interest may be that (s)he doesn't connect the early simple movements of the chair with the potential of going anywhere useful or interesting - a basic understanding of what it means to be mobile being undeveloped. The simple operation of a line follower could reveal the usefulness of mobility with the minimum of cognitive, physical and perceptual demands on the pilot, triggering the motivation to experiment further.

4.2.2 David

Introduction

David was 8.5 years old when he was referred to the Smart Wheelchair project in May 1991. He is the eldest of four children in a family who were very keen that he should participate in the Smart Wheelchair project and that work with the chair should continue at home as well as in school. David was described as having cerebral palsy. He attended a local Education Authority Special School for children with physical disabilities.

Pre-project Profiles

David had both physical and cognitive disabilities. The data gathered by the pre-intervention profile and reported here is based upon functional tests of ability administered by therapy staff (e.g. functional hand assessments); routine classroom tests; and observations of behaviour from staff and parents.

Cognition, attention and memory

David was described as having poor cognitive skills and poor concentration although conversely, he would often latch on to an idea or activity and persist with it. Similarly, some observations noted that his short-term memory was poor, while his teacher said his long-term memory was quite good. It is possible that these variations recorded in the Pre-profile might be due to varying motivation and interest in particular activities.

Vision

David wore glasses and seemed to have no visual difficulties when wearing them. He was thought to have problems with more abstract concepts of colour differentiation and was unable to consistently differentiate primary colours.

Hearing

David was described as having a moderate hearing loss on testing, but he did not seem to have any functional hearing impairment.

Expressive communication

David had a limited and inconsistent number of spoken words. He used a combination of vocalisation, pointing, signing and symbols for communication. He used 20 to 25 Makaton symbols consistently together with around 25 pictures in his Communication Book. He would turn the pages of his Communication Book looking for the symbol but often missed the desired symbol on the page. Nevertheless, once he had found the correct page he could combine symbols to give an instruction. He also used a 32-location IntroTalker which he would use appropriately in a structured session provided it was positioned well and he was concentrating and motivated. His communication was mainly adult-directed and he did not interact much with his peers. He would initiate conversations.

Receptive communication

David used non-verbal cues very effectively in classroom activities possibly to disguise receptive difficulties. In the classroom he would get stuck on a particular topic and ignore questions dealing with a new topic. This could have been due to lack of attention or understanding (see above), problems with reception, or a fear of failure causing him to stick with a topic he knew he understood.

Education

David could differentiate colours of similarly-shaped objects but could not identify colours of differently-shaped objects. He could choose between small and large objects but could not order them by size. He had limited understanding of number and did not know numbers beyond one. He showed some attempts at problem solving using recall.

Social/life skills

David was described as socially immature and shy with strangers, but did show excitement when offered new activities. David attended well in a one to one situation but did not seem terribly motivated to work on his own. He was still wearing nappies.

Mobility/physical skills

David had delayed motor abilities. His motor development appeared to be relatively static and he had not achieved many new skills in the period preceding intervention. He was ataxic and his hand function was poor. He rolled with assistance and sat cross legged with support. He was keen to be self mobile, occasionally showing that he wanted to propel himself in his manual wheelchair. He had tried to use a conventional powered wheelchair but was not able to control it safely or effectively. The staff felt that this was partly because of his physical limitations but mainly due to a lack of understanding.

Initial video interpretation

The pre-intervention school videos confirmed the profile data. It showed David as a child who was alert and quite communicative using a range of different communication skills. However, this was mainly adult-related and he would not make much of an attempt to interact with his peers. He was passive, waiting on questions to be put to him rather than initiating conversation himself. The videos taken at home showed similar behaviours. In one particular video session, he allowed his brothers to take a hat from his head and complained about it through his mother rather than to his brothers. He was encouraged to play with his brothers but was stuck if they moved from room to room, being solely dependent upon adult intervention to participate further in the play session.

School and home settings

David was in a mixed ability group at a Local Authority school for children with motor and moderate learning difficulties. During the course of the project although David had three different class teachers, all were supportive and imaginative when incorporating Smart Wheelchair work into classroom activities. Most of David's classmates were mobile. The classroom area is large although rather cluttered and the majority of the initial Smart Wheelchair sessions occurred in a large area immediately outside the classroom; corridors; and the school gym.

At home, David lived with his family in a bungalow which generally offered enough space for the Smart Wheelchair to be used indoors. Movement from lounge to David's bedroom was difficult due to a narrow hallway, and access to/from the house was limited as the front door did not have a ramp.

Aims and aspirations

The school set out the following aims for David.

General Educational Aims
- to improve perception
- to improve concentration, so that he can be left on his own to do a given task (for example)
- to assess and develop visual skills and hand/eye coordination
- to learn control of a computer game
- to develop understanding of numbers greater than one

Communication and socialisation
- to develop verbal comprehension by introducing specific concepts, for example, verbs, prepositions, big/little, negation, using the IntroTalker, and symbols
- develop two-icon (i.e. sequenced) messages using the IntroTalker
- to develop listening skills and ability to remember and follow instructions (to include tasks involving three simultaneous key ideas)
- to improve communication with peers

Functional mobility
- to achieve functional mobility using a powered wheelchair

Physical skills
- to achieve control of a joystick for mobility and computer use
- to improve sitting balance and posture
- to improve trunk control, head control and hand control
- to prevent contractures and improve muscle strength

Chair, seating and controls design

David had a seating insert for his manual wheelchair supplied by the Bioengineering Centre at Princess Margaret Rose Hospital. A frame was designed and built for his Smart Chair to allow the insert to be transferred from his manual chair. David had demonstrated reasonably good hand function with a paint brush and IntroTalker so a joystick was selected as the most suitable control device. He did not have a dominant hand so it was mounted on the right arm rest. Staff and parents hoped that he would eventually progress to a conventional powered chair so an ordinary analogue joystick was used, gated for forward direction only. To help his understanding of cause and effect, the joystick was modified electronically so that it acted as a switch - either off or on. David started using his Smart Wheelchair in momentary setting with ‘Bump and Stop’ for safety.

Using the Smart Wheelchair

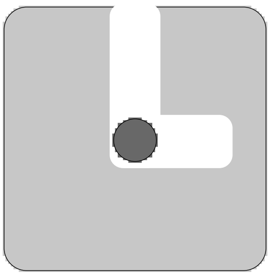
Introduction

In March 1992 David began using the chair with his class teacher approximately three sessions per week. His teacher demonstrated the system briefly and then he drove himself. David practised controlling and stopping the chair in large uncluttered areas and generally showed good control over the joystick although on occasion he would refuse to stop for devilment. After about a week the teacher introduced ‘Bump and Turn’ to give experience of turning. Although this extended the range of games and activities it was not sufficient because David was already showing that he wanted to use the chair for more functional mobility.

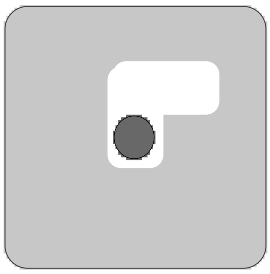
Steering with joystick

Therefore, the joystick was modified give him control over going forwards and turning to the right. However, David had difficulty achieving lateral movement of the shaft despite trying with both left and right hands.

It appeared that one difficulty for David was isolating lateral from extensor arm motion and so the original cross gate (below, left) was replaced by an ‘L-shaped’ item (below, right) which would enable him to achieve lateral movement while still pushing forward. The joystick electronics were also modified to compensate and provide differentiated forward and right turn signals.



Cross gate



‘L’ gate

Steering with switches

This solution was not successful even after time and practice. The team hypothesised that in addition to his physical difficulties, David had incomplete understanding of how the small lateral movements of the stick controlled rotation of the chair. In addition, there was little tactile or visual feedback from the joystick to help him learn this cause and effect. Therefore at the beginning of April 1992, the joystick was re-gated forwards only and David was offered a hit switch for turning right. Although this moved away from promoting joystick skills directly, the team hoped that his understanding would be helped by separating control over moving forward and rotating into two distinct switches. He mastered this format quickly and he was noted to be manoeuvring the chair well around the PE class. By the beginning of May, a left switch had been added and David’s bump tools were changed to ‘Bump and Back Off’. His diary reports that within half an hour he had mastered control of the three directions and had lined up at the door when asked to by the teacher. At this time, the staff noticed that he was making greater efforts to self-propel his manual wheelchair. By June, David was able to drive to the toilet with no help, negotiating a doorway and 90° turn perfectly.

Home use

In July, he took his chair home for the first time. He did small chores at home and enjoyed playing around the house. His parents reported him driving from room to room following his brothers, or going by himself into his bedroom and shutting the door.

Independence

On David's return to school in August to a new class teacher, he was described as being very skilled at manoeuvring his chair. One specific improvement was with his use of the turn switches: when two turn switches were first introduced, he would often press the wrong switch by mistake, only realising when the chair started to turn in the wrong direction. Now he did not even need to look at his tray to target the desired switch: his control was instinctive. At this time, his mother asked if the chair could travel home with him at weekends. She described David's chair as being his best friend and as being his legs and that he basically was lost without it. His parents built a temporary ramp for him to get in and out of the house and the chair was transported on the school bus.

Understanding of functional mobility

David's driving skills seemed to improve and the diary records that it offered David wider opportunities in school and at home. Other pupils were reacting to David's success in his chair: another (non-mobile) child in his class began to attempt to self-propel his manual wheelchair. His mother noted that he liked the feeling of getting dizzy and would sit rotating on the spot for quite some time. During a class visit to the Museum David, was tentative amongst a larger group of people and drove very carefully to avoid colliding with anyone or any of the exhibits. He showed that he viewed his chair as a functional mobility aid as well as a means of having fun by choosing exhibits and driving to them.

Switched joystick control

By November David's hand function had improved and his understanding of mobility and driving was also judged to be well developed. His physical gains were thought to be due partly to practice, and partly to reduced anxiety and less tension. The team thought that a gated joystick would be worth trying again and chose a large Interface Designs device with a long shaft to give a large arc of travel, operating on microswitches to provide audible and tactile feedback. Although the stick's height prevented David from driving right up to tables and did not fit his wheelchair tray, the experiment proved that he had the physical skills to cope with a joystick. At the beginning of December a smaller 'V3 microswitch' switched joystick was provided, modified with an extended shaft and large knob and aluminium four way gate. At first, he seemed uncertain and his driving was quite jerky since he took his hand off when changing direction. He soon learned that his accuracy improved if he kept his hand on the joystick while changing direction.

Interaction

David was described as increasing his social interaction with other children by driving from room to room at break times, joining in play and participating in games during a birthday party in school. The staff noted that he demonstrated his understanding of what was being said to him, by his use of the chair. Meanwhile, the team reduced the length of the joystick shaft and the aluminium gate wore away through use, until David was driving with a standard length shaft and no restricting gate.

Functional mobility

In March 1992, the class returned to the Royal Scottish Museum and David took his Smart Wheelchair with him. He was as mobile and able to manoeuvre about the Museum as any ambulating child. He made specific choices about which exhibits he wanted to stop and look at, preferring technical exhibits (such as motorcycles) to stuffed animals or Egyptian artifacts. By now David had identified himself as being a powered chair user. His diary and chart shows that he was in his chair practically all the time in school and for large periods of time at the weekend as well. He would make visits to other classrooms during breaks and would choose who to sit with in the classroom.

Analogue joystick control

After the Easter holidays in 1993, the team considered whether David could move on to an analogue joystick. His teacher carefully observed his driving for some weeks and noted that he rarely bumped into obstacles and in fact tended to err on the side of caution. A further meeting with his mother confirmed his ability to drive with few collisions. Therefore, the Smart Controller was removed and an ordinary analogue joystick connected instead. During the initial session his teacher gave him verbal support and explanation but David was immediately confident and accurate. A film of this session shows that his control with the analogue stick was superior to control with his switched joystick. Over the Summer holidays he used the chair continually, mastered the power on and off switch and used the chair as an effective functional mobility aid.

Post-project Profile

Personality and cognitive state

David is now described as interacting directly with children in his class. His parents feel that interaction with his siblings is still limited at home although since he is now able to follow his brothers and their friends around the house, it simply seems that sometimes they do not want to play with him. The speech therapist notes that he is a quick learner and seems to remember what he has learned. He can be trusted to move about within the school by himself. His teacher notes improved concentration although his concentration span is still quite short and dependent on the activity and his motivation. David shows greater assertiveness, on one occasion running away using his Smart Wheelchair. He will block everyone's view from the TV set, gaining lots of attention, move off, then return to repeat the mischief. He objects if anyone interferes with his driving and his mother describes him as possibly being more aggressive. However, he is still passive in other situations - for example when someone pressed a button on his IntroTalker he did not actively object even although he did not like it. He likes to succeed and be rewarded for his efforts and to be in control and to use that control in his environment. David can be quite inquisitive. He points to new things in the classroom, driving up to get a closer look. He is very safety conscious and gives sufficient clearance when driving. Pre-intervention he was described as having little motivation. Post-intervention he is much livelier and more independent.

Expressive communication

David's teacher describes him as communicating well, capable of holding full conversations using a mixture of body language, gestures, signing, vocalisation and symbols. He mainly relies on gesture and vocalisations but will use his symbol book if he has difficulty making himself understood. He was recently reintroduced to the IntroTalker again following a period of withdrawal and uses it in more functional, less structured situations than before - for example to attract another child's attention by calling their name. His teacher notes that he is beginning to realise the power of language. He likes to be in control of the group using the IntroTalker and is communicating with more confidence. He turn-takes appropriately and participates in group conversations.

Receptive communication

The speech therapist reports that David listens and answers appropriately, although evidence from the occupational therapist conflicts with this. It is not clear whether this inconsistency is due to him not listening or not understanding. His teacher thought that he no longer got fixed on ideas to the same extent as before. She suggested that this might be because the range of activities which he could tackle and be successful with were far wider than before. The speech therapist notes that he has good contextual understanding and can retain 3 to 4 key ideas during speech therapy activities. David's listening behaviour is variable: it seems to depend on his level of interest in the topic.

Education

David appears to learn things very quickly and seems to be able to remember them. His teacher notes that he can now colour match and sort colours of different shapes. He can picture match and can also match dominoes. He understands large and small but cannot order sizes. His physiotherapist thinks he understands left and right (when using the chair) but the occupational therapist notes that he cannot tell left or right on his body. His problem solving is good in functional mobility situations - for example when planning a route - but his teacher thinks this does not extend to desk activities. In general, his physiotherapist thinks he has improved considerably.

Social/life skills

David is progressing well in his toilet training. He no longer wears nappies, asks to go to the toilet in school and at home he will drive to the toilet door. He occasionally does have an accident, but this is considered good progress from a year or so ago.

Physical/mobility skills

Mother and physiotherapist report that his head control has improved: he holds his head up and looks around more, particularly when in his Smart Wheelchair. His sitting balance has improved a little when sitting on a stool. Sometimes he does try to self-propel in a manual wheelchair but has difficulty because he now has a larger chair. His fine motor skills are still poor and he still requires a scribe. He is showing more of a right hand dominance in drawing and painting. His mother and physiotherapist both report that his control over the joystick and wheelchair have improved immensely and he can make fine adjustments. His functional mobility in the Smart Wheelchair is good. He knows where to go and how to get there. He is generally more interested in other methods of mobility: in July 1992 he started using an Arrow Walker and although he has difficulty using it, he now makes functional use of what ability he does have.

Long term process measures

The Smart Wheelchair Continuity Charts illustrate the patterns of learning and use and the points at which specific gains in control were achieved.

Out of all the children involved in the study, David was allowed the largest amount of regular practice in both school and home settings and this was one of the major factors in his progress.

The chart shows that David had opportunity for regular timetabled practice from the start of the intervention (about three 1 hour sessions per week), rising to every day for long periods after he started using the joystick and two hit switches. This clearly illustrates the improvements in functional mobility resulting from his improved mastery of control. The discontinuity between three times per week and every day occurred when he took the chair home for the first time, and continued when he returned to school after the school holidays. Again, this emphasises the importance of time on task. It also suggests that school staff are more willing to provide mobility opportunities if the child can demonstrate a degree of safe, independent control. The converse of this - that staff may be unwilling to provide practice opportunities for the less able children who need it most - is a real cause for concern, although the tendency is understandable in a busy school. The implication is that service providers of Smart Wheelchairs should encourage home use and aim to provide the child with control over steering as early as possible, both to encourage the child and to convince staff of the child’s emerging skills.

In addition to time on task, other factors affected his learning and these are charted in the Milestones. The steady improvement in control skills was matched by a corresponding development in understanding and appreciation of mobility as a functional activity. Again, the amount and variety of practice was essential in promoting this development.

SequenceView Analysis

David’s pre-intervention profile describes a rather passive child with mainly adult-directed communication and relatively poor use of assistive technology. Staff aims for the intervention centred around providing David with a motivating, powerful activity which would develop his self confidence and assertion, thereby improving his interaction, concentration and understanding. Another set of aims revolved around physical skills, in particular regarding control of powered wheelchairs.

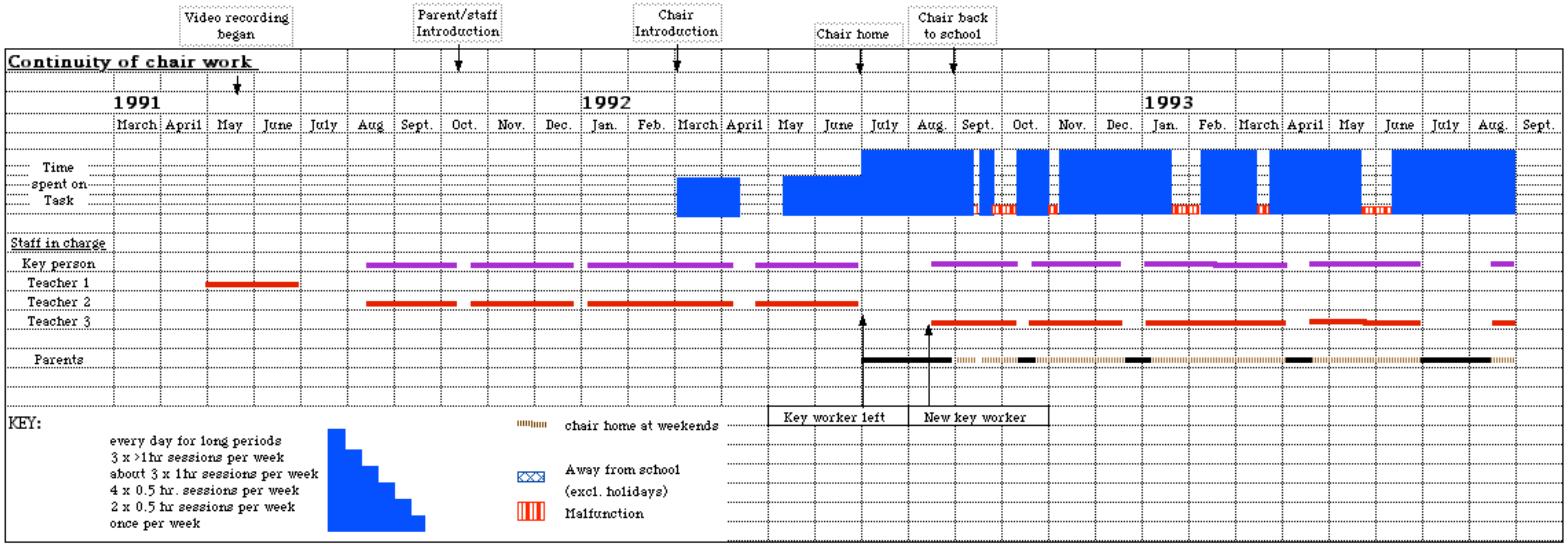
The aim of the *SequenceView* transcription and analysis is to provide quantitative data to clarify qualitative observations of staff and parents. Transcription uses a low-inference event set which minimises (as far as practically possible) undue behavioral interpretations by the human transcriber. These events cover all aspects of the child’s interaction with peers, staff, parents and machines. A straightforward measure of changes in both communication and use of technology (and therefore by inference motor skill) is the number of initiations exhibited by David. Further detail about the effectiveness of the initiation can be obtained by measuring the time taken for response from the human or machine communication partners. To obtain pre- and post-intervention comparisons, this transcription and analysis was performed on two sequences of video.

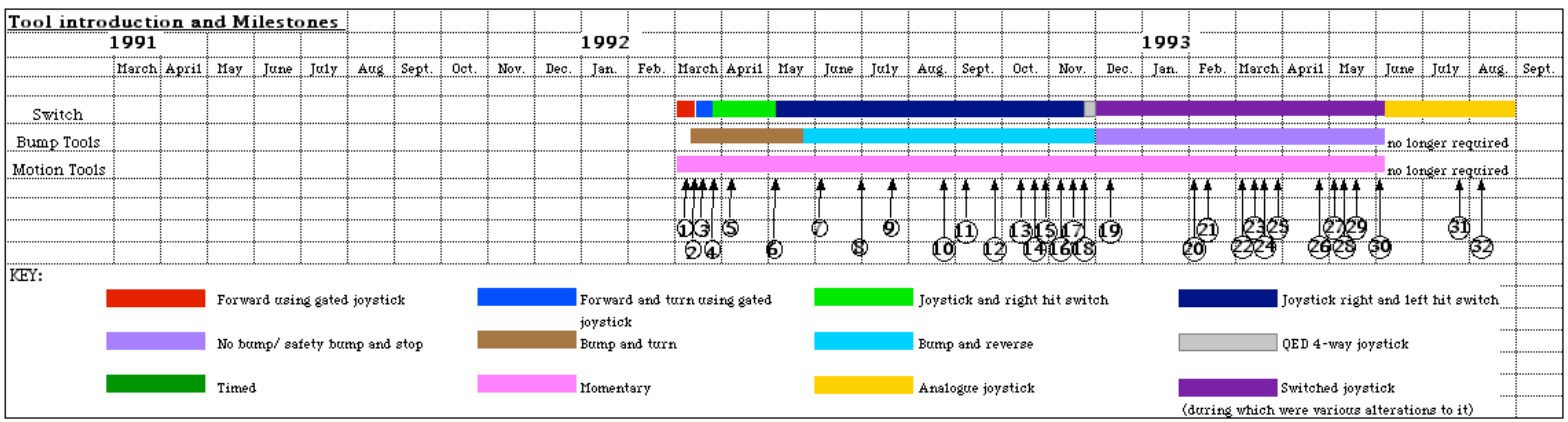
The pre-intervention transcription describes a 22 minute art session when David was asked to paint a house using a paintbrush. In the background another group of children are singing. Most of David's 44 initiations (using gesture and vocalisations) occur in one burst of activity when he is trying, unsuccessfully, to tell the group that his Dad has orange-coloured hair. He only gets 23 responses to these initiations. Communication during the session is mainly prompted by his teacher (78 initiations) to which David responds immediately or quickly 64 times.

The post-intervention video was taken when David was on a class visit to the Royal Museum of Scotland. He is driving his Smart Chair with a four-way switched joystick and as a result is mobile and assertive in making functional use of his mobility. The transcription records only 2 minutes of this session (compared with 22 minutes pre-intervention) and the quantitative differences in interactions are illuminating.

He initiates 28 times during this 2 minute session, compared with 48 times in the previous 22 minute record, illustrating the richness of the environment, his resultant motivation and his ability to initiate by using the Smart Chair as a pro-active tool. There are 46 immediate or quick responses to his 28 initiations (from more than one communication partner), compared with only 23 out of 44 initiations pre-intervention. Taken together, these ratios show that he not only initiates more, but also that he is far more successful in obtaining a response from his communicative partners. Lastly, in the post-intervention record, a human partner initiates only 2 times, compared with 78 times pre-intervention. Comparison of the ratios of David's initiations to those of his partners (44/78 pre- versus 28/2 post-) indicates the difference in his control over the interactions taking place during the sessions. The figures support the subjective impression of David using his new independent mobility to take charge of his environment and set his own communicative agenda.

David


Video recording began
Parent/staff Introduction
Chair Introduction
Chair home
Chair back to school
Continuity of chair work
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Time spent on Task
Staff in charge
Key person
Teacher 1
Teacher 2
Teacher 3
Parents
Key worker left
New key worker
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school (excl. holidays)
Malfunction


Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Switch
Bump Tools
Motion Tools
no longer required
no longer required
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
KEY:
Forward using gated joystick
Forward and turn using gated joystick
Joystick and right hit switch
Joystick right and left hit switch
No bump/ safety bump and stop
Bump and turn
Bump and reverse
QED 4-way joystick
Timed
Momentary
Analogue joystick
Switched joystick (during which were various alterations to it)

****Replace before binding****

Progress Chart (blank side, should be even page number)

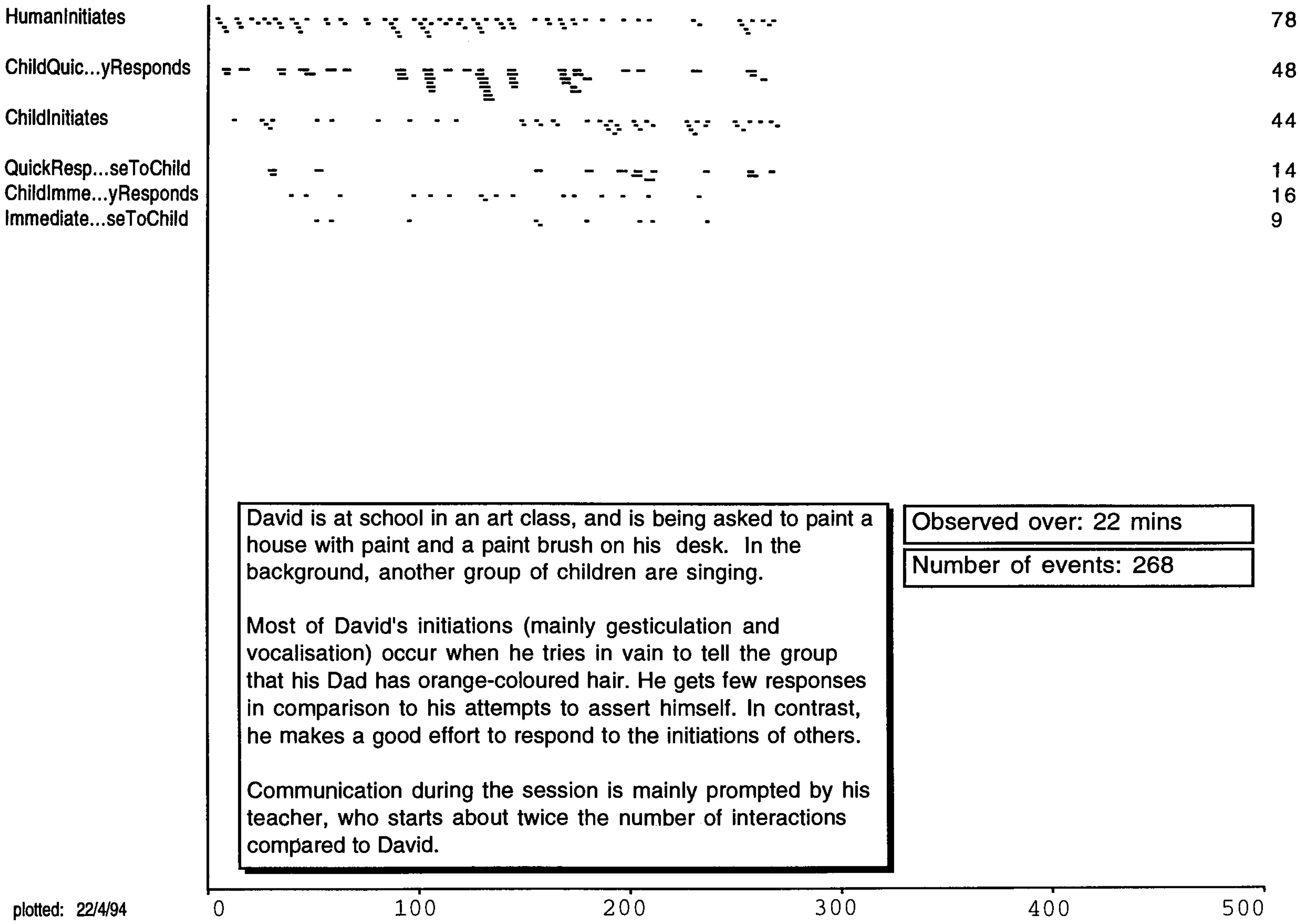
KEY TO MILESTONES

1. David goes solo, managing to stop appropriately.
2. He stops before the skittle, but needs encouragement to bump into it
3. He tries to use his left hand to cope with the gate.
4. He manoeuvres the chair around the PE class well.
5. He drives around the gym, picks up a snooker cue and tucks it under his chin. He drives around the table, and succeeds in potting balls.
6. Within half an hour, he has mastered control of three directions and lines up at the door as instructed by his teacher. On seeing him driving up the corridor, another teacher remarks "I never thought I'd ever see David do that". He is now more anxious to self-propel his manual chair.
7. "He drives to the toilet without any help, negotiating the doorway and a 90° turn perfectly."
8. "He goes to the bathroom and 'performs' on the toilet. This is the first time he has done this at home in a long time and he is very pleased with himself. I ask him to get a towel from another room, and he does so."
9. "He has taken himself to the toilet a few times over the holidays."
10. "After three weeks at home, he went from room to room following the boys and thought this was super fun chasing them up and down the room. He loves the freedom of movement. He can now go into his bedroom and shut the door."
11. "David is 'skilled' at manoeuvring his chair. He is pleased to go to the table to choose an activity in 'choosing time'. He plays a game of stepping stones which helped to prove David's understanding of more complex instructions."
12. "He is asked to go to the toilet, but sees some friends in another classroom. He gives a mischievous grin. This emphasises that David now has the freedom to choose that he did not have before."
    His chair is not working: he shows confusion when the chair does not respond as he expects.
    "He is desperate to go back to his driving position, using his arms to say that he wants his chair."
13. "The chair is not working, and David is very frustrated."
14. The chair is fixed at home. "David is so excited when he has the use of the chair again. He goes round the house, and never seems to get fed up in it."
15. "A pet rabbit is brought into the classroom and David manoeuvres himself into the best position to see the animal. He can take himself to Art at the appropriate time."
16. "It is now noticeable that other pupils are reacting to David in his wheelchair. Another child is realising the mobility potential and wants the freedom and choice it offers even though his is a non-electric chair."
17. "He plays a dizzy game, going round and round for a while. I think he likes the feeling as most children do of getting dizzy."
18. "At the museum, David is a little concerned when there are a large number of people about, but he is very careful and sensible about not catching anyone. Given freedom, he does not rush about from one exhibit to the next, but chooses a few to have a careful look at."
19. *Home*: "He has the new joystick control and uses it confidently for the first time today. It is much smaller and easier to hold."
    School: "He is a little uncertain in his use of the new control but its use seems to be improved if he keeps his hand on the joystick all the time rather than taking his hand away for a few seconds. This causes jerky movements and he has a tendency to knock the joystick rather than holding it."
20. "During his first break time in the chair, he happily went from room to room, joining in the play. Without the chair, he is forced to remain in the position someone else put him in. David is increasing his social interaction using the chair, especially at break/lunch time."
21. "He attended a birthday party for a fellow pupil. His enjoyment of the party is greatly enhanced by the chair as he can move independently to offer the sweets he has made; join in the games unaided; make choices of activity; and demonstrate his understanding of what is said to him by the use of his chair."22. "David manages to drive on to the lift, being 'parked' with help. He is incredibly excited by a large model of the Channel Tunnel drill then drives off to have a look at a model dinosaur. He sees an early model of a train ('doesn't look very like a train!'), points and says 'oo-oo'. He then drives off to look at a car, signs for car and says 'da-da'. He drives on past the skeleton of another car ('doesn't look that like a car') and points, signs and vocalises. He sees the motorbike and gets really excited and vocal; he drives towards it, but stops, turns round to A. and I and points, saying 'dada'. His manoeuvrability is amazing, getting himself into tight alleys not much wider than the chair itself with literally no bumps.
    He joins the other children by the coach, squeezing in so that he can hear, participating in the conversation. He shows no interest in the Egyptian section or clocks, vocalising and pointing out to us the cars on the gallery below. He is really only keen to get back in the lift and is selective about which animals he looks at, vocalising and pointing to the tiger and leopard. He shows some interest in the snakes and lizards, and stops beside an extinct

zebra-like animal, pointing and clicking. He takes a short cut: while the others walked around the corridor, he drives into an exhibition and out the other end."

23. "Mrs. W. is talking to Mrs. P. about the next outing and staffing, saying that R. will use his powered chair. David turns smiling and points to himself."
24. "David is now well established in the routine of socialising at break/lunchtime. He immediately visits the other classrooms to see people and chooses in the classroom to sit next to his friend, R. He is more aware and alert because he can react within his environment more directly."
25. "He is definitely extending his choice in the chair. I've always put him/suggested he go to a certain place in the group next to one pupil in particular. David makes a very definite choice not to sit there this week, but to sit at the other side of the group near the biggest boy in the class with whom he has formed a friendship."
26. "David is well established in Smart chair use and is far more independent. He can take himself places, but is still very careful in positioning his chair in a group and never bumps into anyone or anything. At times, he is perhaps over-cautious."
    "He is making his wishes felt more and is expressing choices more."
27. "He is still proficient in 'driving' his chair, but I feel the very fine control he had has been affected by the alteration in the joystick. Since the stem is shorter, David can no longer hold it in the same way and his control with his hand over the top is not as good."
28. "He chooses to leave the room while I am speaking to someone. He is very excited at break-time and would rather rush around visiting his friends than eat his snack. He often doesn't wish to waste valuable 'free' time eating when he could be moving around with friends: this has not happened before."
29. "His new joystick has a slightly longer 'stem' which is better for David to control since he grasps underneath the knob at the top rather than bringing his hand over it."
30. "David is playing with his sailing boat at the paddling pool in the back garden along with other children. He is pushing the boat and moving it around the pool to catch it and push it away again
    He is immediately confident using an analogue stick and finds it an improvement on the switch connection. The chair responds to his control better. David always errs on the side of caution when using his chair and manoeuvres very carefully around objects and people. He is reluctant to come too near to a table for fear of collision and usually allows a generous distance and is very reluctant to come closer."
    "When asked if he would like control of the on/off switch, David is delighted."
31. "David uses his chair whenever possible throughout the holidays and spends some time in the garden whenever the boys are playing outside. Inside, the chair takes him to and from the toilet when necessary. He helps slightly, taking different things to the bedrooms. He presses the on/off switch very well and misses the chair when away on holiday. He is very excited on returning home as he can now 'drive' again."
32. "He is now very confident with the on/off switch on his chair. He uses it appropriately and controls it well. He manoeuvres well: the only difficulty he may have is to see behind him when he reverses. He does not do this much and usually goes slowly so there are no accidents. He can have difficulty in physically looking behind him, but has no difficulty guiding his chair through the most crowded session."

David (Pre-study) 18/6/91



David is at school in an art class, and is being asked to paint a house with paint and a paint brush on his desk. In the background, another group of children are singing.

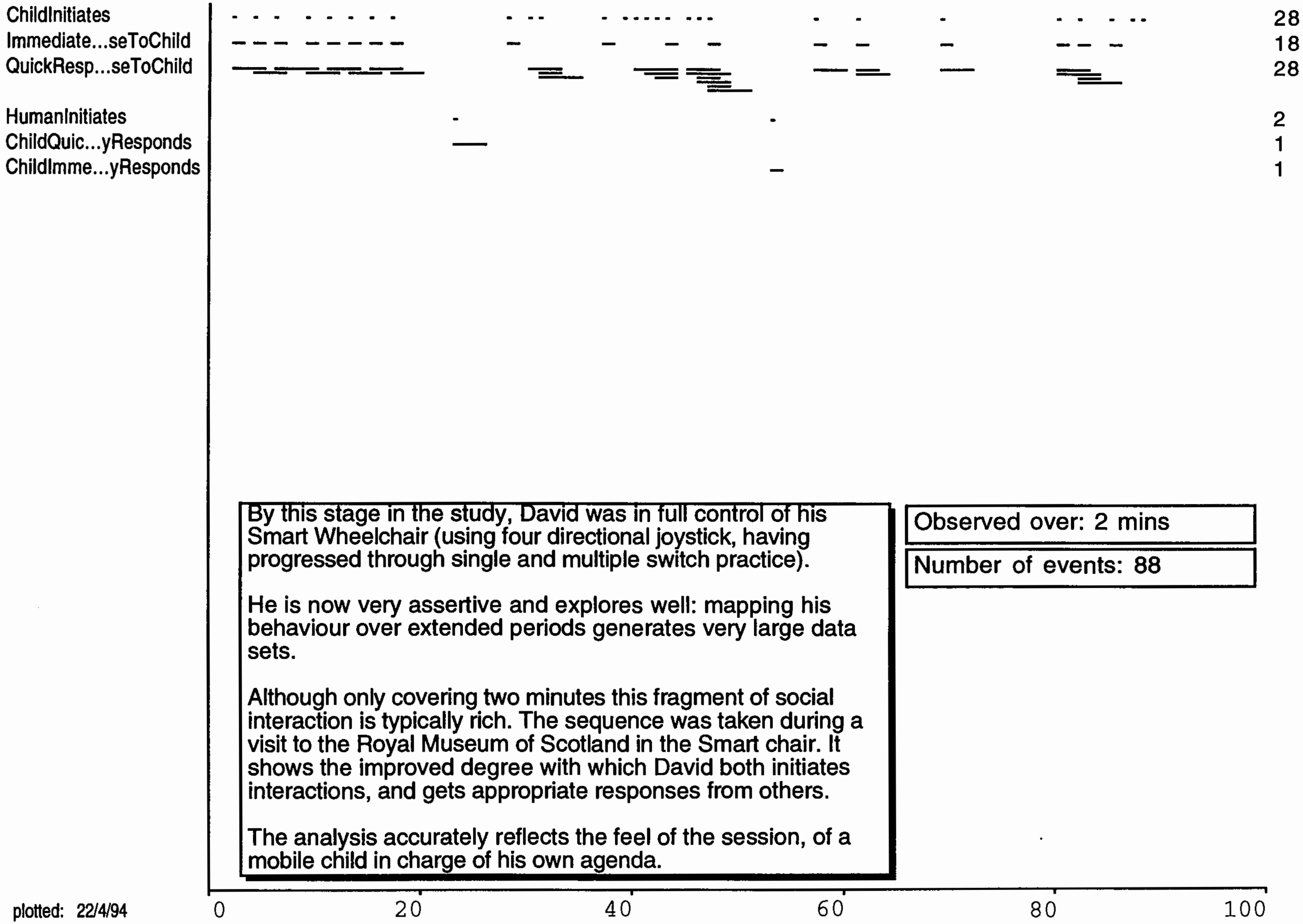
Most of David's initiations (mainly gesticulation and vocalisation) occur when he tries in vain to tell the group that his Dad has orange-coloured hair. He gets few responses in comparison to his attempts to assert himself. In contrast, he makes a good effort to respond to the initiations of others.

Communication during the session is mainly prompted by his teacher, who starts about twice the number of interactions compared to David.

Observed over: 22 mins

Number of events: 268

David (Post-study) 5/3/93



By this stage in the study, David was in full control of his Smart Wheelchair (using four directional joystick, having progressed through single and multiple switch practice).

He is now very assertive and explores well: mapping his behaviour over extended periods generates very large data sets.

Although only covering two minutes this fragment of social interaction is typically rich. The sequence was taken during a visit to the Royal Museum of Scotland in the Smart chair. It shows the improved degree with which David both initiates interactions, and gets appropriate responses from others.

The analysis accurately reflects the feel of the session, of a mobile child in charge of his own agenda.

Observed over: 2 mins

Number of events: 88

plotted: 22/4/94

4.3 Group 2: Training for Augmented Powered Mobility

4.3.1 Stephen

Introduction

Stephen was 11.5 years old when he was referred to the Smart Wheelchair project in March 1992, and was the younger child in a family of two, his older brother being of working age. He attended the senior section of an Edinburgh special school, which he had attended all his school life, and knew well.

He suffers from athetoid cerebral palsy, with great problems controlling any limb. Stephen was thought to be quite an aware child, but he had problems maintaining eye position thereby making his vision difficult to assess. He was a non-speaker, communicating only through a consistent yes/no response to structured questions.

His parents were supportive of the Smart Wheelchair project, but didn't have very many expectations that Stephen would succeed. Nevertheless they were anxious to provide him with the opportunity of using the Smart Wheelchair.

Pre-project Profile

Stephen is a very disabled boy, and his disabilities have profoundly affected many aspects of his education, communication, and home life. Teacher, parents and therapists contributed to the profile, sometimes relying on other data like the Jordanhill assessment results, but mainly inferring his abilities from functional observation.

Personality and cognitive abilities

Stephen was described as a generally happy boy who quite often was mischievous. He seemed to like rough and tumble and playing with toys, but his tolerance of being handled in rough play did not extend to acceptance of facilitation techniques. He could be impatient. Stephen would show his emotions clearly, frequently getting agitated if unhappy or upset: in this state, he might react by biting, and did not always stop when bidden to do so. He showed a little inquisitive behaviour.

Sociability

Stephen was described as being quite unsure of unfamiliar situations or people and did not mix well with children outwith the school, becoming withdrawn and quiet.

Vision

Stephen had spectacles to correct a squint, but used every opportunity to remove them. His gaze was fleeting and this constant eye movement hampered his ability to fix on objects. Nonetheless, he could look for and locate desired objects (his mother reported that he knew and could recognise his toys by name since, during his bedtime routine he would say good night to each of the toys individually looking in their direction as each was named).

Hearing

No hearing defects were reported.

Expressive communication

Stephen expressed himself using limited gaze and vocalisation. He used a consistent yes/no response, eye pointing accurately to a thumb up for yes and a thumb down for no and would withdraw from a situation by closing his eyes and turning his head away. Stephen would raise his right arm to indicate turn-taking. Despite the fact that the classroom team used his yes/no response for choice making, neither of his parents felt that they had had any success with his yes/no response and therefore said that he didn't make choices in his home life.

Receptive communication

Stephen reacted appropriately to conversations in and around him, was aware of voice tone, and tried to organise himself in response to being asked to do something.

Educational development

Stephen had established object permanence: he would attempt to pick up toys if they had dropped from his view. His Jordanhill profile showed him to be aware of body parts and their names.

Mobility/physical skills

Stephen does have some saving reactions, putting a hand before him if falling, but his muscle tone was generally low and movement jerky which made them difficult to control. He tended to use gross swiping movements. With help he could sit and move from a sitting to a standing position. At home he used a Linburn Walker, but this was not functionally effective. Some positions distressed him: Stephen had a great dislike of lying both on his front and on his back.

Initial video interpretation

The pre-intervention school videos showed Stephen as a child who was very much inhibited by his uncontrollable movements. Triggered by any intentionality on his part, random movements would increase, inhibiting him from doing whatever he had set out to do. Despite this, he still persevered: video sequences show him trying to imitate the movements of other children during their therapy, and he will persistently try to handle object placed near his grasp (to the extent that staff felt the need to control his hand movements, and tended to seat Stephen with his hands tucked down by his sides).

The home video showed Stephen being fed on his mothers knee, and being brought toys, mainly for younger children. These sessions placed few demands upon him.

School and home settings

Stephen attends the senior section of a grant-aided school for children with special needs. His was a classroom with areas of wide open space, although the school itself is an old Victorian building with a long narrow corridor and little other space to allow exploration or play. His teacher runs a formal timetabled structure and was keen that Stephen’s Smart Wheelchair sessions would not be disruptive to the other children in his class.

At the outset of the project, Stephen and his parents lived in a bungalow. His mother felt that his chair could be used in the living room and up and down the hall without too many problems. In addition, the back garden was paved and so Stephen could be given the opportunity to play outside on good days. The chair went home for the first summer holidays. Unfortunately, the family moved house at the end of the first year, and the chair could not be taken to the new home.

Aims and Aspirations

Stephen’s school staff identified the following curricular and therapeutic aims. These were derived from written goals built into his individual learning programme, and were not specifically directed toward, or integrated with, Smart Wheelchair activities.

General educational aims

- to expect consistent cooperation and participation in all areas of the curriculum
- to increase awareness and anticipation of routine events and sequences of events
- to increase enjoyment of various types of music
- through therapy, to encourage Stephen’s ability to communicate through music
- to develop picture/object recognition
- recognition of the voice of an adult or familiar peer in a group, finding them with his eyes
- to encourage listening to simple instructions, and attempts to carry them out
- to have Stephen able to operate his own toys and increase his ability to use a switch
- to increase his self, body, and peer and environmental awareness

Communication and socialisation

- to develop pre-linguistic skills, particularly listening skills
- increased peer and familiar adult interactions through eye contact and vocalisation
- to look in response to a familiar person
- to encourage a smile in greeting with eyes open
- choice making by eye pointing
- to develop the use of a consistent yes/no response
- attending to general language stimulation
- to develop language comprehension

Physical skills

- to encourage positioning of head in the midline
- to encourage hand/eye coordination
- to encourage Stephen to initiate interaction through vocalisation and eye contact
- to work on tracking skills
- to encourage sitting balance
- to encourage weight bearing through upper and lower limbs
- to control involuntary movements

Functional mobility

In addition, it was thought that Stephen would benefit from the Smart Wheelchair by

- increasing his motivation
- offering him purposes for movement
- increasing his independence
- increasing his opportunities to interact
- increasing his control over his environment and increase choice
- developing and improving motivation for switch work
- encouraging development of concepts of space, size and the relationship of objects to each other, and lastly
- developing the basic skills of planning and sequencing.

Chair, seating and controls design

Stephen's manual chair seating was not suitable for transfer to the Smart Wheelchair and so an individual seating system was built for him by the Princess Margaret Rose Hospital Bioengineering team. A tray was also built to accommodate any switching that would be required.

Because Stephen had such problems controlling his arm movements, the school staff felt that he would not successfully target a switch, and initially requested joystick control. Stephen also had a tendency to play around with anything placed on his tray, and the fear was that he might displace or damage wires or the switch itself: this pointed to a firmly fixed control system. School staff favoured a joystick with a T-bar, preferably supporting whole arm movement during operation. The suggestion was that his left (control) hand should be strapped into a guttering device which would restrict all unwanted movements in his forearm and wrist, while his right hand was tied down, grasping a small handle secured to the tray.

Given the fears about control, Stephen began with a timed motion tool and the 'Bump and Stop' collision tool. He began work with these systems in June, 1992 with a full month of approximately two sessions per week with his helper.

As with other children, he began his chair work sitting on his helper's knee, but partly because of his size and uncontrolled movement and partly because he seemed to be happy with the chair, he quickly progressed to driving the chair solo. In these early sessions, he had a tendency to repetitive operation of the control, taking no account of the fact that the chair had been activated.

Although the chair went home for the summer holidays, it was used quite infrequently there. There was therefore a considerable gap in the early timetable of intervention.

However, development of a suitable control proved very difficult, and the period between June and the end of October had been dogged with joystick problems. The joystick was just not robust enough for Stephen and it frequently had to be repaired or strengthened. With each strengthening came a reduction in the versatility of that particular joystick design. To achieve the right strength, degrees of freedom were being sacrificed, until it could only be used for moving forwards.

Chair work increased considerably after returning to school in late August. Stephen was beginning to make some functional use of his very limited mobility: during that term, his diaries record him interrupting his travels to view pictures on corridor walls, and stopping to look in other classrooms as he was travelling around the school.

Around this time, Stephen had shoulder straps added to his Smart Wheelchair seating which stabilised his trunk (and also foiled his attempt at operating the switch with his nose, his forehead and his chest.)

By his general increase in awareness of his environment Stephen was showing signs that he was ready for directional control. At the end of October, both CALL and school teams were convinced that, poor limb control or not, alternative strategies were needed. It was decided at the beginning of November that he should try a large target switch. This was velcroed to the tray, and at the same time, Stephen changed from using a timed tool to a momentary motion tool. This way, his tendency to strike repeatedly at the switch would get him little reward - he would have to learn to maintain his hand position on the switch in order to achieve movement.

This combination seemed immediately to be much better and Stephen very quickly learned how to make the chair move using his new switch and new motion tool. He did, however, still find it very difficult to control movements when he became very excited and didn't particularly like to have an audience (i.e. the video camera). Chair work was still isolated from other aspects of the curriculum during this period. Sessions tended to be carried out with him withdrawn from the classroom and was limited to driving down the corridors of the school.

The staff were reluctant to make further changes, although the project team believed that steering was becoming much more important. It was March before the introduction of a further switch was agreed to. The move was made in two stages. Firstly, the team decreased the size of the single switch system, to get Stephen used to smaller targets which would be needed as the numbers of switches increased. Stephen did not take terribly kindly to this at first, and became very agitated. However, by the middle of May, and when left to his own devices, he showed that he could manage to operate the smaller target switch effectively.

In mid May, the second stage took place. Stephen was introduced to a primitive notion of steering, by way of another target switch on his tray. He proved himself physically able to swivel his arm from one to the other, and work began on developing his directional skills, including planning, control, and visual attention. Part of this was achieved through interactive games with his speech therapist, placing particular emphasis on visual location and tracking

Just prior to the summer holidays of 1993, Stephen managed to steer the length of the school corridor non-stop.

After the period of the evaluation had finished, Stephen's chair was fitted with a Line Follower, with the aim of giving him more functional ability. It was hoped that it would increase his opportunities for play and exploration.

Post-study profile

We report only changes in the profile, which was made up by the same team members who had provided the pre-study assessment.

Personality and cognitive abilities

Stephen's Smart Wheelchair work revealed his liking of being outdoors, where his freedom is greatest. Indoors, he showed inquisitiveness and exploratory behaviour when using the Smart Wheelchair, stopping at doors to look into classrooms. Stephen proved himself to be assertive: he would push someone out of the way when he was in his Smart Wheelchair in order to pass him, and seemed to like to drive ahead of the member of staff he was with. The class team in general felt that Stephen's confidence had increased over the last year although it had a tendency to regress if he was absent from school.

Sociability

Stephen reacted differently in and out of his Smart Wheelchair. Out of it, he likes to be part of a group. In it, he dislikes crowds (and has pushed people out of the way in protest).

Vision

The class team felt that Stephen's visual skills had improved. When securely seated, he has developed a better ability to observe, and also keeps his eyes open for longer periods of time. Stephen's eye contact is much better. He tracks people or objects effectively, both at close and long range. The class team also reported that a large step forward in the Smart Chair was that Stephen kept his head up more; his eyes were open; and he was looking much better.

Expressive communication

Stephen's eye contact was reported to be much better and his eye pointing has continued to improve. This in turn has led to easier and more powerful choice strategies, reducing reliance on 'thumbs up' or 'thumbs down' signals. However, his mother still feels that he doesn't have consistent yes/no responses at home.

The class team also reported improvements in Stephen's appropriate use of vocalisation. Although more assertive, he is tolerant of turn taking needs of others in the class. Moreover he will attend to the person as they take their turn, looking at them directly. Stephen's improved eye pointing has not yet transferred to any other form of functional communication, i.e. an eye pointing board.

Receptive communication

Although still very difficult to assess because of the poverty of functional acts which are open to him, there were signs that Stephen now anticipated conversational events better and could relate them to what was taking place around him. Much of the chair work relied on some level of verbal instruction, and Stephen seemed to respond appropriately to these. He was less reliant on prompting.

Education

Despite Stephen's success with the switch system on the Smart Wheelchair, he has not yet shown any interest in using switches with anything else in his classroom or home setting. It may be that it is too early for such transfer to take place. Or it may be a side effect of the lack of integration of chair work with other activities: Stephen may not have made the link between his achievements in one situation and possibilities in another.

Physical and mobility skills

Stephen appears to have increased limb control, and an awareness of his own ability to influence unintended movements. For instance, after being reminded that he will drive better if he is calm, there is a definite change in the control of his arm movements.

Reports both from home and school suggest that Stephen's head control has improved in general. This improvement has also influenced his eye-pointing and visual abilities, and through them, his communication.

Stephen is mobile in the Smart Wheelchair. He can maintain continuous movement from the top of the school corridor to the bottom and has definitely grasped the function of the steering switch. These efforts have taken time, and we consider him still to be in the motivational phase of Smart Wheelchair work. The task now is to shape his enjoyment of mobility into functional skills.

Long term process measures

Stephen benefited from a stable environment during the project. The staff and the school setting remained constant throughout the work. As a result, the project team were able to be of maximum use to the school team as they developed their own skills.

A long term goal for Stephen is independent functional mobility, and he is far from that goal yet. Nonetheless, he has made some solid progress towards that goal, and there is no reason to suppose that his improvements will not continue. Related to the staff's functional mobility aims for him, his achievements include

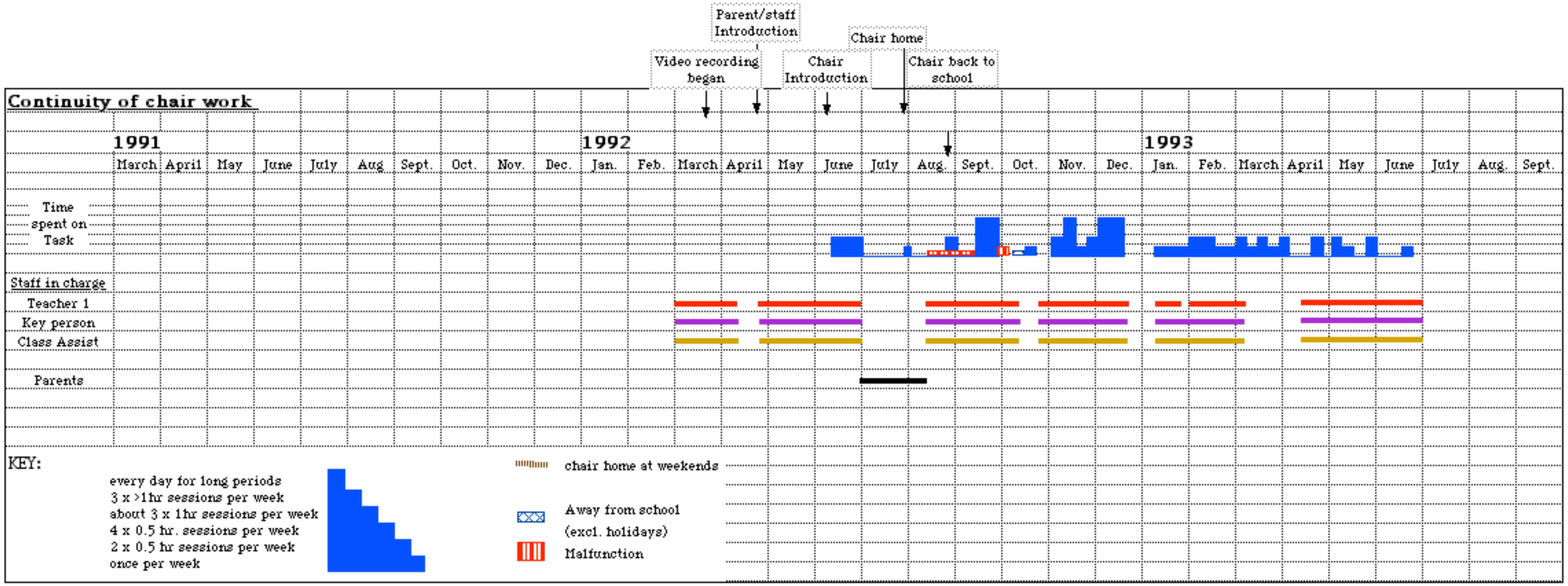
- increased motivation
- emerging understanding of the potential and usefulness to him of independent movement
- some early steps toward his independence, through his autonomous control of the Smart Wheelchair
- increases in his opportunities to interact, which he is exploiting
- increases in his environmental choices and control
- improved motivation for switch work, and effective uses made of such controls.

The next steps should build on these foundations to

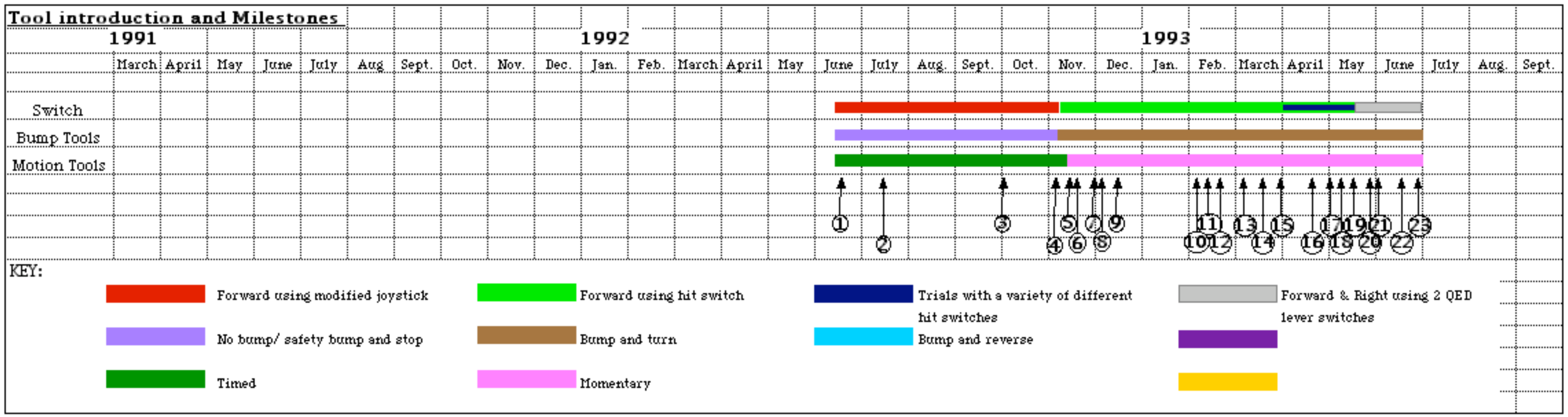
- encourage development of concepts of space, size and the relationship of objects to each other
- developing the basic skills of planning and sequencing.

To do this, the team feel that closer integration with day to day classroom activities are needed. As the process chart shows, Stephen's achievements have been made through one or two sessions per week of about a half hour per session, away from the classroom setting. Functional improvements will happen when the opportunities for practice increase, and when these are related to other curricular and therapeutic goals. At that point, transfer of skills (such as his switching abilities to other computer-based-learning or augmentative communication tools) can also be better encouraged.

Stephen



Parent/staff Introduction
Chair home
Video recording began
Chair Introduction
Chair back to school
Continuity of chair work
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Time spent on Task
Staff in charge
Teacher 1
Key person
Class Assist
Parents
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school (excl. holidays)
Malfunction



Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Switch
Bump Tools
Motion Tools
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
KEY:
Forward using modified joystick
Forward using hit switch
Trials with a variety of different hit switches
Forward & Right using 2 QED lever switches
No bump/ safety bump and stop
Bump and turn
Bump and reverse
Timed
Momentary

****Replace before binding****

Progress Chart (blank side, should be even page number)

KEY TO MILESTONES

1. Stephen goes solo.
2. Stephen looks around when moving backwards.
3. He is very interested in the pictures on the wall, but not the photographs. He also likes to look in the other classrooms.
4. Stephen quite obviously does not want to play hide and seek with a furry white rabbit and chooses instead to hide a train.
5. Stephen is given the hit switch and plays about with its position on the tray. R. shows him how momentary works and he starts flailing about a bit although he appears to be much better if no-one talks him through what he is to do.
6. He manages to drive down the corridor in one movement.
   "When asked if he is leaning on the switch, he immediately sits up straight."
7. "He stops at every door to look in and giggles when he realises he can do this."
8. He becomes conscious of the video camera and "giggles when the operator tries to hide further up the corridor. He finds out he can use his nose to work his switch and thinks this is very funny."
9. Stephen is initially agitated during rehearsal for class play. At one point during the performance, he is so excited, he cannot operate the switch.
10. He enjoys a chair session, driving the chair to choose toys for his classmates.
11. "Coming back up the corridor, he has to get past the trolley and D. He just lifts his hand and pushes her and finds this quite amusing."
12. "He does very well although he is still [repetitively] banging the switch now and again."
13. "He tries his new switch, but there is so much going on, he is not able to concentrate." "He does very well on the way down, but not so well coming back; his arm is down and he seems very angry when asked to bring it up."
14. "His head control is not as good as it can be. He does not vocalise at all today, but seems interested in his surroundings."
    "His head control is very good today. There is no vocalisation, but he gives very nice looks when meeting people."
15. "Another switch is tried today, but Stephen is not really in a terribly good mood. He uses his chest, head, nose, or anything but his hand in order to operate the switch. There is a lot of moving switches about. He is generally quite angry, but is better when his own switch is put back on the tray. This could imply that it is the change of switches which is upsetting him. He is then given R.'s switch set-up and another switch."
16. "Stephen bumps into M. knocking her into Mrs. T's office; he finds this very amusing."
    "He goes in search of an apple and pictures in the corridor, but finds it quite difficult. He manages to find one, but is too excitable today."
17. "He walks with me to the top of the corridor. I walk on ahead, allowing him to follow on. He stops at every open door to look in."
18. "The shoulder straps from JL's chair are tried today and this looks much better. Previously, he had to make an effort to sit up and keep his head up. His head is often down on the tray and the switch operated thus or by his chest."
19. "Stephen plays around with both switches, and enjoys turning. He looks for me when I am hiding behind him and laughs when he turns and sees me. The shoulder straps remain in a good position and I think help Stephen maintain a more functional position, with his head up more often and his eyes opened wide. He has a short spell of being close and looking well at me. This is the best session I have had with Stephen; he is showing interest in his surroundings and is prepared to go off on his own."
20. "He is much more confident with better posture, enabling him to look around. He is using B.'s switches at the moment, but they are not very secure as he is able to pull at them. Stephen's head is up most of the time and he seems a lot happier."
    "He is encouraged to look in the different directions available, e.g. passage to right or doorway ahead to indicate where he wants to go. He does seem to want to go outside and this is a favourite activity. As before, he has periods of [random switch] hitting and agitation, and then periods of activating the switch much more calmly when he appears to relax and take in more of his environment. He makes a definite attempt at searching when I hide at end of corridor: head up, eyes open for 4/5 seconds."

21. I hide in various doorways and call to him, jumping out and saying 'boo' which he enjoys immensely. Only the forwards switch is used initially. Once in the hall, I show him the other switch and he does several circles. He is encouraged to use his eyes to look for me each time he comes round. He seems to understand about 'big eyes' and enjoys the game of making big eyes to encourage me to come nearer and see them close up. He has periods of excitement and accidentally hitting the switch still. I explain to him that holding his switch on calmly makes the chair go better. He decides to go outside to look for T.'s dog. He laughs a lot at me whistling and shouting for the dog. There is better, smoother switch action by the end of the session.
22. "He starts at the top of the corridor, puts his hand on the switch and sets off. He doesn't stop until he reaches the office. I then point him in the right direction and off he goes. He is very calm and confident today."
23. "He looks at the pictures on the wall, and is very relaxed and confident. He is still not sure about his right turn switch."

4.3.2 Jack

Introduction

Jack was referred to the Smart Wheelchair project in May 1991. At six years old he was the youngest child in a large family who were keen to participate in the project, but were not so keen to have the chair at home. He frequently stayed with a 'Share the Care' family who were also enthusiastic about his participation in the project. Jack attended a local special school run by a national charity. He is spastic diplegic with dystonia, has good head control and gross motor movement but little fine hand control. He was described as a sociable child who talks continually.

Pre-project Profile

Personality, cognitive state and sociability

Jack was described as a highly sociable little boy. He was very responsive to his surroundings, talking about what he saw and about anything and anyone new although he was also cautious in unknown situations. He could be easily distracted and seemed to have a short attention span. He occasionally used opting out behaviour, frequently requesting to go to the toilet. Jack demonstrated good memory, remembering the words of songs and anticipating the events during the daily routines. He was quite assertive and often wanted to take charge of the group, saying "I want to be in charge"; "I want to do it myself".

Vision

Jack had a slight visual defect and wore glasses in the classroom.

Hearing

Jack's hearing was unimpaired.

Expressive communication

Jack was able to initiate and sustain conversations. He was described as "chatting incessantly" and would shout your name to gain your attention. He knew several songs, was able to give relevant instructions when in charge of a group song, and could imitate several different accents. He indicated choice by eye pointing or naming the object of his choice.

Receptive communication

Jack followed conversation at his own level, but his understanding of adult conversation was inconsistent. He was described as too distractible to listen and respond appropriately to stories. He could follow two stage commands. He responded to an angry tone of voice but relied on the situation as a guide to appropriate behaviour.

Education

Jack had grasped the basic concepts such as size, position and object permanence. He was also able to discriminate and name primary colours. He had understanding of cause and effect and demonstrated some problem solving abilities. He was reported to have difficulty transferring knowledge from one task to another and was very easily distracted.

Mobility and physical skills

Jack had good head control and could sit with minimal support for a short period of time. When excited, he tended to go into a mass extensor pattern and his muscle tone increased more distally with lower trunk tone. He had limited voluntary movement, mainly over his upper limbs, with scrabbling action in both hands. He was able to 'commando crawl' over a very short distance only.

Initial video interpretation

The pre-intervention videos taken in school show Jack to be a child who is extremely aware of his surroundings. He was able to capture his audience before delivering his request for his message. He did, however, tend to get quite fixed on certain ideas and would ask the same questions time and time again, never seeming to comprehend the answer. He loved rough and tumble games and was frequently heard asking if he could do something himself. The initial videos taken of him with his Share the Care worker show similar behaviour.

School and home settings

Jack attends the Junior Department of a grant-aided school run by the Scottish Council for Spastics. The team that put together his initial profile changed before Jack began the Smart Wheelchair work. His classroom was large and cluttered and his new teacher was concerned that Jack would be a danger to the other pupils if he worked in the classroom. Most Smart Wheelchair sessions therefore took place in the hall area of the Junior School, an access area to all the other classrooms in the school and therefore open to interruption. The class itself operated a structured timetable and initially Jack was only allowed chair sessions once a week for a short period of time. As time went on, Jack did have extra play sessions in his chair at lunchtimes.

The school team anticipated that Jack would only use the chair in a limited way and so it was decided that he would share his Smart Wheelchair with another child in the Junior School (William). This child later became a member of his class. The chair was not expected to go home with Jack and the staff intended that it would be primarily for the use of the other child in the classroom.

Aims and aspirations

General education aims
- to increase his attention span
- to improve colour recognition

Communication and socialisation
- to improve concentration in music
- to improve his listening skills
- to encourage turn taking in conversations
- to extend Jack's spoken language
- to try to interest him in pictures and photographs
- extend his awareness of when it is appropriate to communicate
- to develop anticipation of group activities and follow the correct sequence of events
- to increase the complexity of the instructions given to him
- to improve peer group awareness

Functional mobility
- to have more control of his own environment and increased independence
- to provide him with the opportunity to visit rooms, other people and to go messages
- to improve sitting balance and encourage rolling and independent mobility on the floor

Physical and life skills
- to encourage Jack to wear his glasses and increase his tolerance of them
- to improve feeding patterns
- to improve attainment of independent skills, appreciating his limitations
- to encourage weight bearing
- to encourage bilateral activities.

Chair, seating and controls design

Jack did not have an existing seating system for a manual wheelchair and therefore the Bioengineering Centre at Princess Margaret Rose Hospital built a seating system with tray, based on a modified Britax car seat.

Jack's poor hand function and tendency to scrabble meant that he had difficulty targeting and releasing conventional lever switches. A joystick was chosen so that he could grasp and lock his hand on, then use gross arm movement to activate the switch. A suitably sized analogue joystick was used, modified with a forwards-only gate and electronics to provide a switching action (on the basis that a switched control system is easier to understand initially). A T-bar was fitted to give him a more secure grip by separating his thumb from his palm, providing a reflex-inhibited position for his hand. The joystick was located on a tray slightly right of midline to be accessible to his right hand (although no dominant hand had been identified). Jack's first sessions used timed motion and either no bump tools, or 'Bump and Stop' for safety.

Using the Smart Wheelchair

Introduction

The team had intended to introduce Jack to the chair gradually, but this was quickly abandoned in the face of his enthusiasm: he wanted a 'go' before his Smart Wheelchair was prepared, asking to drive it himself before he had even seen it working. Jack set the agenda during his early, single-switch experiences, asking to be turned in a different direction after hitting obstacles. At first he thought the spoken feedback from the speech synthesiser was funny and each time the chair synthesiser reported to him, he would burst into a fit of giggles.

Veering

As shown by the Continuity Chart, Jack's chair started behaving erratically a few weeks after it was introduced. In particular, the chair veered away from the straightline which caused obvious problems for Jack as a single switch user. The Smart Wheelchair Database shows that higher tolerance components were fitted to the Smart Wheelchair interfaces and a software offset added to compensate for the veer. Bugs were found in the bump tools software, and the collision sensors had some mechanical damage. Lastly, the DCL wheelchair motor controller exhibited a fault and was replaced. These malfunctions were disruptive: the only positive benefits were communicative. Jack would reprimand his 'bad' chair and discuss the faults. He showed his motivation to use the system by his efforts during the session; by his objections to ending it; and by his conversations about his chair which 'speaks'.

Bump and Turn

In March 1992, Jack had 'Bump and Turn' added to his chair. He soon anticipated that, following a collision, the chair would reverse and turn and he would talk along with his speech synthesiser, reporting what the chair was about to do. At the same point momentary control was introduced. A few weeks later, the staff allowed Jack access to the chair during unsupervised lunch and break times. This mixture of supervised, structured sessions and unsupervised free play was thought to be important in developing Jack's confidence.

Steering in one direction

The school staff required persuasion from the research team to introduce a turn switch (chosen in preference to gating the joystick because of more obvious cause and effect), and when steering was finally offered in June 1992, it was adult controlled. His helper would offer him the switch only when she thought it was necessary, and would decide whether the turn was to left or right. The rationale offered for this restriction was that the staff wanted Jack to prove he could control turning before they would allow him to use it. The research team could not persuade the staff that the most effective way for him to learn and demonstrate his skills was through practice, nor convince them that his steering was almost certainly better than the chair's 'Bump and Turn' tool. After some time the turn switch was fixed permanently to his tray to provide right turn, with 'Bump and Turn' giving a turn to the left. The diary records that his driving was improving (Milestone No. 8) despite this limited practice.

Steering in both directions

At the end of April, Jack was finally given another hit switch to turn left. During the first session he began by playing with the new control, but soon demonstrated his abilities with it by driving himself to the boys' toilet without help. His functional use and accuracy continued to improve and he became skilled at driving in quite cluttered environments.

Staff attitude and assessment

The Formative Evaluator reported a considerable increase in staff enthusiasm for Jack to use the chair after the second switch was introduced, and it seemed that this was because they perceived him to be driving appropriately and independently (even although it is likely that he *did* possess these skills at an earlier stage, but was not allowed to demonstrate them). A diary entry in May 1993 (Milestone 12) notes that Jack was ready to use the chair in a classroom situation. Jack began to take charge of his mobility as a result. If a problem occurred, he would shout to the staff that his bumpers were not working or he was stuck in the toilet and so on.

Home use

In July 1993, the chair went to his 'Share the Care' volunteer during the first two weeks of his school holidays. Video taken prior to the holidays showed Jack to be a proficient driver who was able to drive competently and make fine adjustments using his three switches. The Continuity Chart records that his weekly use jumped from two half-hour sessions per week while at school, to three sessions lasting more than an hour. Later in the holidays the diary records that he was driving on most days (and was frustrated with the chair's limitations on pavements and outdoors).

Jack's attitude

Although Jack's control was now very good, he did not use the chair as a full and complete functional mobility aid. He perceived the chair as a special activity with a beginning and an end to each session so that although he could make good independent use of the chair while in it, he would ask to be taken out of it after some time. His understanding of the capabilities of the chair was still dubious: on one occasion he asked his helper if he could go up stairs in the chair.

Epilogue

In January 1994 approximately six months after the period of formal recording ceased, a new speech therapist started work with Jack. In February she asked if a switched joystick could be provided as she thought his physical control was now sufficiently good to attempt joystick control. A stick was supplied based on a standard 'V3 microswitch' type, but it was not sufficiently robust and the shaft with T-bar rotated in the socket. This meant that Jack had difficulty grasping it. Nevertheless, on the basis of only a few sessions the staff felt that he had the ability to use a suitable joystick and the Bioengineering Centre are manufacturing a more robust device from scratch.

Post-study Profile

Personality and cognitive state

The Class team report that Jack is more confident in unfamiliar environments although it also depends on his mood. His attention to some tasks, particularly driving, is thought to be better, but he is still very distractible. Pre-intervention his long term memory was good, and the post-profile describes it as excellent. He remains assertive and seems more persistent particularly when driving, although he shows frustration if the Smart Chair gets stuck or is faulty. He shows a desire to have more independence and tackle tasks by himself, although is sometimes unrealistic about his (and his chair's) abilities.

Expressive communication

The class team report that Jack's language has improved. He uses more complex sentences and verbs appropriately. He also uses directional terms (left and right) freely and appropriately. He is persistent when communicating. His speech is usually appropriate although if he has something on his mind he won't listen to what you have to say to him and can still offer quite bizarre answers. One staff member noted that he is a difficult child to start a dialogue with because he does not listen well.

Receptive communication

The team report that it is difficult to separate his seeming lack of comprehension from his lack of auditory attention. Jack seems to have more understanding of prepositional concepts. It is thought he can understand and follow up to three information carrying words. He has some difficulty recognising or perceiving pictures of objects, although he has no difficulty in identifying the object itself.

Education

Jack's understanding of different forms of cause and effect is judged to be better through his use of switches to control the chair. The staff report that there are indications of improvement in problem solving but only when driving the chair (although whether this is a new development or simply an empowerment of existing ability is hard to tell): it does not appear to transfer to other situations.

Physical and mobility skills

The class team report a general improvement in his fine motor skills (although they are still poor), illustrated by the use of more switches. With the hit switches, he still 'swipes' but is more controlled and can maintain switch closure. His sitting balance and head control are thought to have improved. His upper limb function has improved and this has enabled crawling on the floor. The staff report that Jack likes the Smart Chair and would be in it all day if he had the opportunity, although this is contradicted by diary entries from his 'Share the Care' worker which report him asking to be taken out of the chair after 30 to 40 minutes. Nevertheless, the class team now consider him a candidate for a powered chair whereas previously he was never considered. They felt that Jack had been more successful in the Smart Wheelchair than had ever been anticipated.

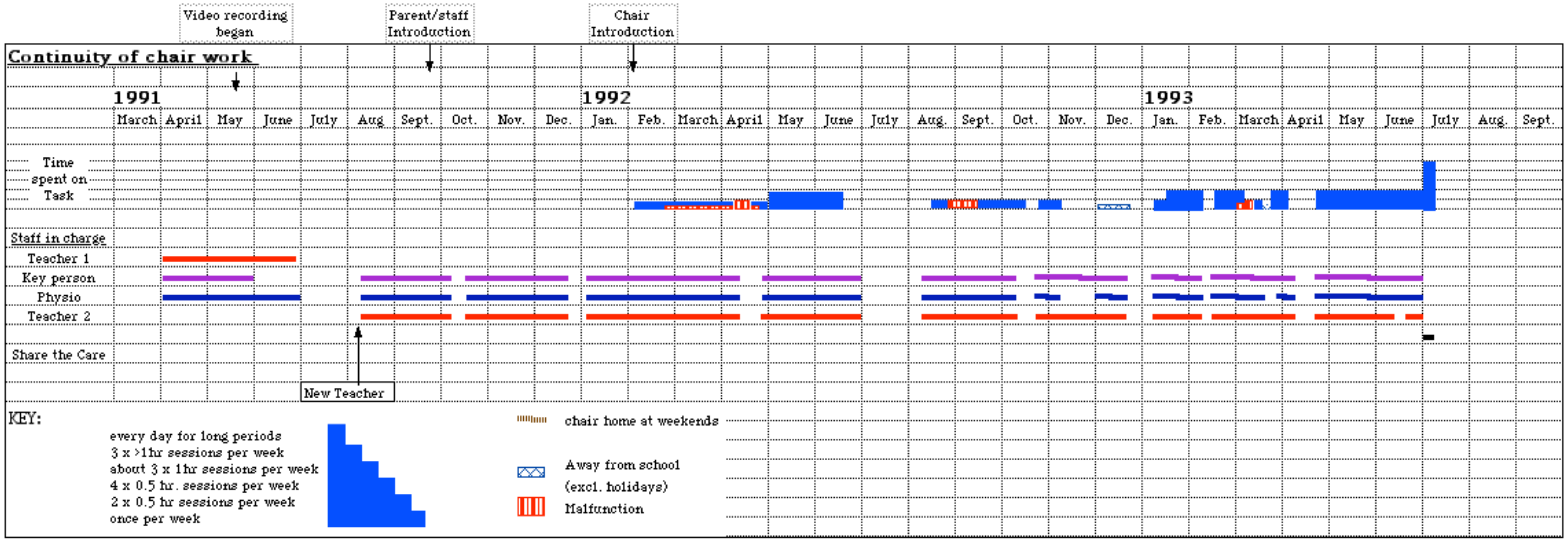
Long term process measures

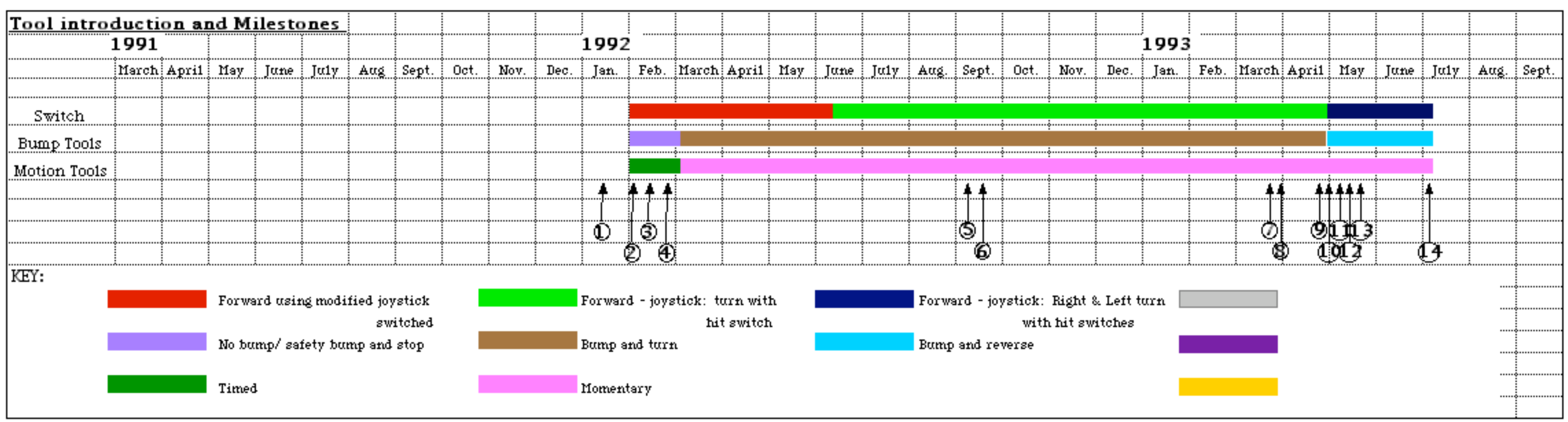
Jack's Continuity Chart shows that although his access was regular, it was limited. This lack of opportunity for practice was compounded by periods of chair malfunction, by the chair being shared, and by initial lack of access during the school holidays. The increase in use at the start of the school holidays in July 1993 is due to efforts by his 'Share the Care' worker.

Despite the lack of practice, Jack made steady albeit slow progress in his acquisition of new skills and control of the chair for functional mobility. The long periods between presentation of new tools prevented Jack from tackling new challenges and consequently from developing new skills. This is illustrated by the clusters of progress Milestones around the times when new opportunities were offered, at the introduction of the chair in January 1992, and in May 1993 when the second turn switch was added.

Intentionally blank

Jack


Video recording began
Parent/staff Introduction
Chair Introduction
Continuity of chair work
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Time spent on Task
Staff in charge
Teacher 1
Key person
Physio
Teacher 2
Share the Care
New Teacher
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school
(excl. holidays)
Malfunction


Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Switch
Bump Tools
Motion Tools
1 2 3 4 5 6 7 8 9 10 11 12 13 14
KEY:
Forward using modified joystick switched
Forward - joystick: turn with hit switch
Forward - joystick: Right & Left turn with hit switches
No bump/ safety bump and stop
Bump and turn
Bump and reverse
Timed
Momentary

****Replace before binding****

Progress Chart (blank side, should be even page number)

KEY TO MILESTONES

1. At the seat fitting, Jack asks, "Can I have a shot? Can I drive? Who'll push me?"
2. Before helper has even sat on the chair, Jack asks, "Can I have a turn?". Jack puts his hand out to have a turn, and he goes solo. "I want to turn."
3. "The chair's talking!"
4. His final comment on leaving the chair in the hallway is, "I've parked".
5. During the time the chair is away to be repaired, he asks why the chair is not speaking to him. He tells A. that she is going backwards on the school bus: she was sitting in a rear-facing seat.
6. He asks to drive to the Snoezelen and it is explained that it will take a long time. His response is "Can I try?".
7. "He is encouraged to come towards me while I keep changing my position in the room. He uses the chair and switches appropriately to turn."
8. "He turns the chair 180°, requiring only a little guidance from me."
   "He uses both Right switch and Forward alternatively to correct his direction, and needs very little help or guidance."
9. "He wants to go into the hall and manages independently most of the way. Once in the hall, he wants to go to the girls' toilet and manages to get there with no help. Twice the chair switches itself off without my realising it and Jack has to shout over to me that the chair is not working. Left to 'experiment' on his own, he manages to disappear into the cupboard where he shouts 'A., help me, I'm stuck … I'm in the cupboard!'."
10. "Introduce Left switch and explain its use. He is able to use it appropriately, but is more inclined to play with it initially. It is better at lunchtime: he makes his way into the class next door and to the boys' toilet with no help."
    "Jack is desperate to go outside in the Smart chair. He copes really well with new Left hit switch but is unable to go completely independent due to the uneven sloping surface and small chips in the tarmac which prevent the wheels turning. Jack does not like being helped and tells me 'not to help' on several occasions. Unfortunately I have to help for safety reasons."
11. "He wants to go into the hall and is allowed to do so. He is left on his own and uses Left and Right switches appropriately. Jack reports 'chair is not working well'. As it turns out, the bumper needs fixing. Also, each time the chair switches itself off, Jack shouts to tell me 'it's not working'."
12. "He manages to negotiate the physiotherapy door independently. Getting out of the physiotherapy room is quite difficult as it involves going through a narrow opening. I think Jack is ready to use the chair in a classroom situation rather than on a 1: 1 basis. He is using the left and right switches appropriately."
13. "He is told to go to the toilet himself when he needs to go. Due to lack of time, he is given a little help to get there, but is able to go from the class to the toilet independently. He shows this during informal lunchtime sessions with Smart chair."
14. Jack helps to set the table. "He goes from the lounge through the door into the hall, collecting items (one each trip), turning in a fairly confined space, through the lounge into dining room. He has to manoeuvre round several corners (making both right and left turns) and this encourages him to travel short distances without bumping into anything. He is also careful not to drop the item on his tray. He uses his Smart chair each day to move around downstairs in the house. He helps to carry various items, and goes to the television to turn it on/off when requested. He goes into the hall to collect letters, newspapers etc."
    "He chases the dog!!"
    "Jack chooses when to come out of his chair; it varies each day but he is in it for approximately 30 - 40 minutes. He is most frustrated that the chair does not work in the street."

4.3.3 Adam

Introduction

Adam was first selected for the Smart Wheelchair project in April 1991, when he was 12 years old (although it was May 1992 before he began his Smart Wheelchair work). Adam was described as suffering from a right hemiplega and being prone to frequent seizures. Throughout the project, he was living in a home for children with multiple disabilities run by the local Health Board. Despite his being away from home, his family were keen that he should be involved in the project. They took an active part in putting together his pre-study profile and attended the introductory courses. However, they made no input into the post-study profile.

Pre-project Profile

Adam is a very disabled child. The clues needed to judge his cognitive, social, and other skills are quite subtle, and were mainly drawn from observation of Adam in functional settings.

Attention

Adam was described as having a variable attention span although it was felt that this was largely dependent on his moods and his seizure pattern. The class team felt that he could often be coaxed back to participate after his attention was lost.

Behaviour

He was also prone to challenging behaviour at home, but less frequently at school: for example, he would nip or hit anyone in the vicinity.

Sociability

Despite his challenging behaviour, Adam was described as a quite sociable boy, interested in his surroundings, and preferring situations where he could see what was going on. For example, his dislike of being in the ball pool was attributed to his not being able to see anyone over the edge of it. He also likes being handled or touched and especially being cuddled.

Memory, motivation and social interaction

Adam's challenging behaviour gave helpful insights into his skills and abilities. The staff were confident that Adam could estimate distance well (which would be needed for wheelchair control) since he knew, for instance, when he was near enough to someone to nip them. He was able to attract attention to himself by hitting the table and on the odd occasion hitting himself in order to gain attention. Adam also understood and remembered people and situations, reacting appropriately (if disruptively). Adam attached meaningfully to familiar people or situations when expecting to be disturbed, and brightening for people that he hasn't seen or heard for a while.

Adam could anticipate well during a turn-taking game. He would watch his classmates, lifting his head up ready for his turn. He responded better to extrinsic, adult encouragement than to the intrinsic reward of achievement: solitary computer based learning was not a good way to learn, say, switch control.

Sight

Adam had little or no sight in his right eye, and tracked objects only in the left field of vision.

Hearing and understanding

There seemed to be no evidence of a hearing problem. Adam would search for the origin of a sound, could recognise familiar voices, and responded to whispers.

Expressive communication

Adam's expressive communication was limited to non-verbal demonstrations of upset, pleasure or annoyance, with some (unconfirmed) eye pointing and reaching. Adam initiated communication by hitting the table in order to attract attention, or by using a scream or a non-verbal vocalisation. His teacher felt that he made good attempts to turn take in a group situation and even better when in a one to one situation with his teacher. Efforts were being made to teach signing, with very limited success.

Receptive communication

Adam seemed to recognise his own name and the names of his family and familiar people. He would make eye contact if someone spoke to him.

Education

Adam had already shown an understanding of direct cause and effect using switches in computer based learning tasks. However, his demonstrated problem-solving abilities were restricted to rolling over or kicking in order to move himself into range to be able to nip or kick someone. His abilities to plan using chains of reasoning or to deal with time-deferred problems were unproven.

Physical/mobility skills

Adam sat up well and was also able to pull to sit. He was also able voluntarily to turn his head although this was mostly to his left. He was walking with one person supporting him. He could cross leg sit using his right hand to help his balance.

For manipulation, Adam tended to use his left hand although there was some evidence that he was beginning to try to use his right (he would occasionally use it to bang on the table for attention). In general, Adam's right hand was held in a tightly flexed position at both elbow and wrist joints, and was not used. He showed evidence of some fine motor skills in his left hand: he would use a pincer grip to nip people and yet would use a gross hand movement in order to pick up crisps.

Initial video interpretation

The pre-intervention videos confirm the staff profile, showing Adam as having a complex mix of developed and undeveloped skills. He was a child with some obvious physical ability (for example, his fine hand control when feeding), and yet an inability or unwillingness to extend or transfer his physical skills into other functional areas. He tended to be an observer in a group situation unless prompted by an adult.

School and home settings

Adam began his Smart Wheelchair project in a mixed ability class at a Regional Education Department special school for severe multiply disabled children. His classroom environment consisted of a small, rather cluttered classroom and a larger, also space-constrained, eating area (with obvious implications for the Smart Wheelchair work). He later moved into another classroom which, whilst also constrained, had a large open shared area outside the classroom door. Also available to the classroom teacher from time to time was the school gymnasium: another large open space.

Adam does not live with his family. Home is a large Victorian building with a spacious, infrequently used playroom, a lounge area (with little free space), and bedrooms. There was also a large tarred area outside which his nursing staff intended to use for Smart Wheelchair work during good weather. Towards the end of the project, the nurses from Adam's home requested that the chair might come home with him. They were trained by the project team, and the chair went home for the occasional weekend.

Aims and Aspirations

The school set out the following aims for Adam.

General educational aims

- extending understanding of cause and effect
- encouraging self-motivated exploration, and through this, build up awareness, understanding and independence
- engaging Adam in activities which would promote attention to his surroundings, and allow better assessment of his sensory skills
- developing self help and cooperation in hygiene

Communication and socialisation
- to encourage self-assertiveness
- understanding (and responding appropriately to) simple instructions based around classroom tasks focusing on mobility
- to encourage one on one interaction in class
- to encourage and develop responsiveness in class group work
- to extend Adam's ability to make and communicate choices, and to transfer these to basic signing skills
- to improve attention to other people's communication, focussing on his understanding of simple verbal direction and gesture

Functional mobility
- to develop autonomous mobility used appropriately: e.g. in directed classroom tasks, independent explorations, and social acts

Physical skills
- to ensure that Smart Wheelchair activities did not prejudice development of existing physical skills (independence in swimming and in walking)
- to improve sitting and standing balance
- to develop strength, confidence and coordination in fine and gross motor skills.

Assessment and adaptation - chair, seating and control design

Adam had adapted seating for his manual wheelchair but as this was not transferable to the Smart Wheelchair, the PMR Bioengineering Centre designed and built an individualised seat for him. This proved to be rather difficult because Adam is a very tall young man and he had large feet which interfered with the bumpers. The final seat design was quite high off the chassis (which had the advantage of putting him into a commanding position, near to the height that he would have been had he been standing up). In addition, a tray was added to his seating.

Because Adam had previous experience of using a hand-operated contact switch, it was decided that this switch would be the control device in the initial stages of Smart Wheelchair work. The switch was placed centrally, allowing Adam to use either his left or his right hand. The switch was velcroed to the tray in order to prevent Adam from accidentally sweeping from the tray; in the event velcro was not strong enough and the switch (and its successors) were bolted to the tray.

The chair was initially set up in Timed control mode and with a ‘Bump and Stop’ tool.

Using the Smart Wheelchair

Adam began using the chair in May 1992, with the early sessions sitting on the knee of his helper (to build his confidence). Because of his size, this was an extremely difficult process. Fortunately, Adam was not disturbed or upset by the experience, and went solo after two sessions. Going solo was also not frightening for him.

Adam's early use of the Smart Wheelchair coincided with his Physiotherapist’s programme aimed at preventing further deformity to his right hand using a hand splint. Whenever he was wearing the splint, he preferred to hit the switch with that hand, and, by the end of June 1992, he was using his right hand nearly all the time when he was driving his chair.

Despite the fact that Adam attends a 52 week school, the disappearance of his regular class teacher at the end of June meant that there was no chair work done between then and her reappearance after the school holidays - in fact until the middle of September. Adam was introduced to ‘Bump and Turn’ (which gives some directional freedom) in September. To prepare for two switch control (allowing more directional control still), the size of the current switch was reduced. Adam would need the time to practice on a smaller target. (Using a smaller switch would also force Adam to locate the switch rather than randomly bang at the tray. It was noted in his diary about this time that he was not actually looking at the switch: he was hitting it and, when the switch was taken away, he continued to hit the tray.) After the new switch was given to him, he often missed it in this situation.

Adam's chair work now decreased in frequency and seemed to be dependent on a member of the CALL staff actually being present during a chair session. Despite these reduced opportunities to practice, his preference for using his right hand continued to be obvious and he began to show an interest in improving his chair control, making efforts to stop his chair to pull or touch things that were on the walls.

In mid-November, it was decided to try to decrease Adam's unproductive banging at his switch by changing his motion tool to momentary. The idea behind this change is that frequent short strikes on the switch would get Adam nowhere; he would have to maintain contact with the switch in order to get the reward of movement. His initial reaction was to lose interest in movement for a few minutes, but he soon became involved in what was going on and showed that he understood that he had to maintain switch contact to make the chair move.

By the beginning of 1993, the CALL team were trying to encourage the classroom staff to give Adam the opportunity for directional control by giving him another switch, but the class team were reluctant to take the step. Frequencies of practice sessions remained low.

During February and March of 1993, Adam was unwell and therefore was not using the chair in school. It was May before he returned to a more regular routine. Again, the CALL team tried to persuade the classroom team to give Adam a change of direction: in June 1993 he was given another switch to enable him to turn right. Up until the summer holidays he spent much time spinning in circles on the spot, to his obvious enjoyment, and the faint frustration of others.

Post-project Profiles

Adam's post-project profile was prepared by pretty well the same team who constructed his initial profile, with the exception of his parents. We concentrate on the changes in the profile. Not surprisingly, given the limited time on task revealed by the diary record, areas of perceived improvement are limited.

Personality and cognitive abilities
Staff reported a distinct decrease in Adam's attention seeking and challenging behaviours: he screams and spits less, and is less vicious in attacking other people.

Exploration
On a larger scale, Adam's exploration of the world is showing signs of purpose. Arriving at a non-human obstacle, he will now examine it. If he causes a corridor jam, he expects some social interaction with those he is inconveniencing.

Communication
Staff report a slightly better communication in other settings, with more tolerance and occasional interaction when in a group.

Physical skills and mobility
His therapists report a decrease in Adam's gross motor skills possibly due to his increasing seizures and the effects of the drugs used to control those. As a result, Adam's walking has deteriorated, as has his standing ability.

One major, positive change in Adam since the initial profile is the use of his right hand. He chooses to use his right hand where he never did before and transfers this skill to other, non-chair settings: he will, for example, now use two hands together in the sand pit. He will also attempt to reach out and hit people with his right hand and is generally showing a marked preference to it, for example, using it with the tambourine. This can be with or without the splint.

Long term process measures

The Smart Wheelchair long term process observations both reveal patterns of learning (and the opportunities for doing so), and indicate specific gains at the points where mastery of chair control leads to new tools being added, or chair control being reduced. These processes are summarised in the table overleaf.

The table shows Adam to have had very little opportunity to practice - the reader should compare the long term profile with those of other children. Despite that, Adam made some significant steps:

His ability to learn new skills (and remember them even over the long gaps in training) are shown both by his mastery of switch control, and his adaptability to the changes in tools and controls imposed during the study.

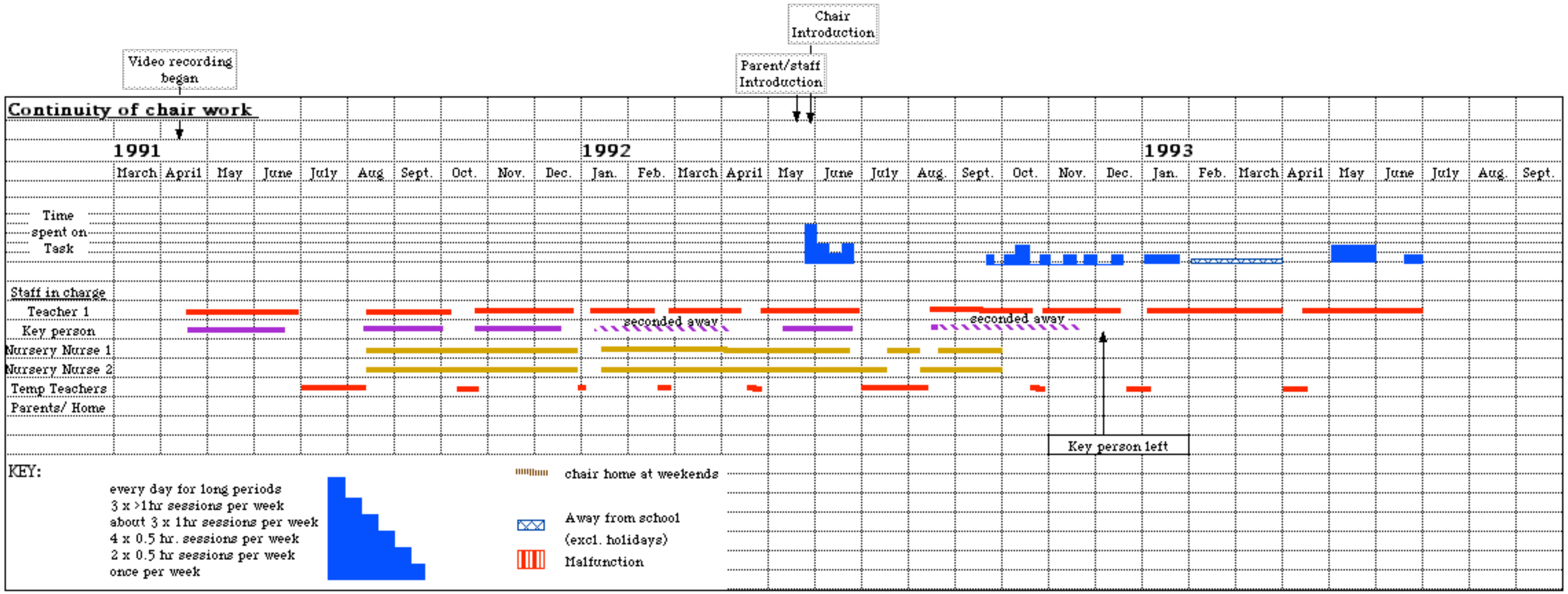
He will now put more effort into exploring his own abilities. For example, his attempts at switch control using his previously less preferred hand and his adaptability of hand control are both new.

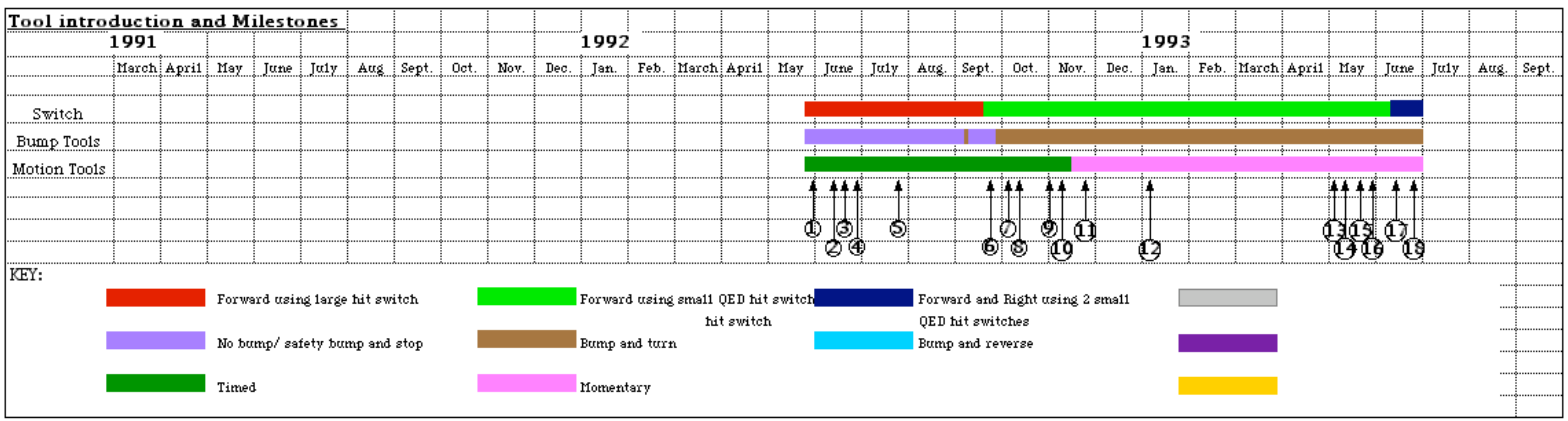
Adam shows an ability to concentrate on (to him) rewarding tasks: his enjoyment of the new turn manoeuvre using a second switch resulted in useful lengths of control practice. No adult extrinsic reward was needed.

To be effective even in these very limited examples of play and exploration, Adam has demonstrated a much finer grip of causality than previously. His awareness of the inconvenience of others due to him is a first step to planning for more taxing driving situations in busy environments, and shows his ability to de-centre.

Any child with enough random movements can appear to operate a Smart Wheelchair, operating the controls by chance. Adam has shown his control to be well beyond that, using features of the chair effectively in play and exploration. This embryonic functional use is still primitive, though, and is being slowed in development by several factors. The major ones are: physical illness; limited integration of Smart Wheelchair work into the curriculum; and, as a result of both of these and timetabling problems, a lack of opportunity to practice.

Adam


Chair Introduction
Video recording began
Parent/staff Introduction
Continuity of chair work
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Time spent on Task
Staff in charge
Teacher 1
Key person
Nursery Nurse 1
Nursery Nurse 2
Temp Teachers
Parents/ Home
seconded away
seconded away
Key person left
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school
(excl. holidays)
Malfunction


Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Switch
Bump Tools
Motion Tools
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
KEY:
Forward using large hit switch
Forward using small QED hit switch
hit switch
Forward and Right using 2 small
QED hit switches
No bump/ safety bump and stop
Bump and turn
Bump and reverse
Timed
Momentary

****Replace before binding****

Progress Chart (blank side, should be even page number)

KEY TO MILESTONES

1. Adam solo, problems mainly to do with his size: he was eager to go alone.
2. Adam seemed to be motivated - hitting the switch and laughing.
3. Adam's right hand in 'cock-up' wrist splint - now using right hand to hit the switch.
4. Adam using right hand practically all the time when in the chair - as we left the gym, he accidentally knocked the door with his hand, then deliberately hit it a second time to show he had control?
5. Asked Adam if he was having fun in his chair - laughed. Chair on the move practically all the time.
6. Adam now not looking at the switch when hitting it - if switch taken away continues to try to hit where it was: because new switch is smaller, often misses it.
7. "…reluctant to start moving today. However, after a while, he was hitting the controller with both his left and his right hands. Adam seemed to be showing off to a couple of women who encouraged him to keep moving, which he obligingly did without much hesitation…in the beauty therapy room, Adam was having his face cleaned, obviously to his displeasure, judging by his facial expression…he decided (still being in his Smart chair) that he wanted to move so he frantically banged away to try to get some peace, *fortunately for S. (who would have been hit) the power was off*" (report by staff - our emphasis).
8. "…seems as if he was keen on using the chair this afternoon as he rarely stopped for a long break…used right hand - 3 in a row on the way up and down the gym to join us".
9. "Sat up well in the chair, couldn't wait to start, right hand on the go immediately - 3 times in a row. Then bump and turn round the room with giggles all the way. Responded well to the "admiration" of his audience. Out to the area to move round, again in control and enjoying his audience. Even when we finished he was ready to go with his right hand again. Right hand seemed to be dominant for switching (splint on again- now back to using main splint). Only tried once to move the switch - more keen to be on the move".
10. "Adam was all set to go, used right hand by chance to set off - chair did not move - right hand again - no go - right hand x 2 - no go, 1a good hit with the left hand. Quite obviously having chosen to use his right hand with no result, Adam resorted to his left hand. Then waited for the chair to be ready and just time to move off - used right hand too."
11. "Adam was relaxed and happy to be in his chair hitting the switch constantly. Stopping on occasions to touch/pull things on the walls. Enjoys banging his left hand on doors as he passes them."
12. "…initial reaction was one of disinterest with the movement for 5 mins. However, with a little encouragement, Adam soon became involved. When Adam reached the gym area where Group 4 were involved in an activity, he stopped and showed great interest in what was going on before continuing on our way."
13. "Adam was bright and alert as they set out, looking round (thinking no one behind?) - and using right hand with the splint to access switch. Smiles for R. and people met in corridor."
14. "Adam started off at a great rate - right and accessing again and again - quite determined taps. In the gym Adam turned to see D. - used left and right hands."

    "Came under parachute and pulled it with left hand, but accessed switch to move the chair with right hand."
15. "rather than being left out of an activity, he would make an attempt to turn his chair round and re-enter the circle. Once in the circle, he became involved in a game of trying to run over staff…made great use of his right hand, also his left hand for banging on windows and doors"
16. "…jam-ups cause most fun - good interaction here. Outside, Adam was content to look round…fun again causing a hold-up - just looked round and giggled"
17. "Adam started with left hand -and moved through area 2-3 slowly - taking time to look round, then another touch of switch. left hand helped bring up right hand to switch - in red carpet area A enjoyed a bump/turn time - stopping to watch anyone passing through and enjoying a 'chat' when possible. Again switching with right hand, using left hand to knock doors, pull parachute. NB use of right hand to switch allows freedom for left hand to be used independently"
18. After some help to put his right hand on the right turn switch, he hit it a few times. Played interactive games with him, standing out of his field of vision trying to encourage him to turn round and make eye contact. He didn't use the forward switch at all, but kept going back to the right turn, laughing as he was doing so.
19. "first moves were short sharp turns using his right hand (in splint) to control the chair. After 5 or 6 attempts he had turned the chair 180 degrees and was facing the opposite direction from where he had started. At this point, he headed in a straight direction from where he had started. At this point, he headed in a straight direction this time controlling the chair with his left hand. He ran into a table after travelling approximately 12 feet without stopping…continued this circling motion on several occasions"

4.3.4 William

Introduction

William was 6.5 years old when the project started. He is the youngest of a family of three children. His parents were supportive of the project, keen that William should have the chair home during the holiday periods and saw it as a means of giving William some independence. William had recently transferred from the Nursery Section of a grant-aided school run by the Scottish Council for Spastics, to the Junior Department full-time. He has dystonic quadriplegia and a bulbar palsy. He was described as a bright child and with no visual or hearing impairment. His communication skills were limited to eye pointing and some vocalisation.

Pre-project Profile

Personality, cognitive state and sociability

William was described as sociable and liked one to one situations. He could also be moody, petulant and manipulative and when disinterested would refuse to respond or participate. He had a good attention span and showed assertiveness within his physical capabilities. He has good memory of people, objects and situations, anticipating situations during the morning programme or during stories. He had good eye contact when communicating but was not particularly motivated to eye-point to his communication board, preferring vocalisation. William was quite frail and he was frequently off sick at home and for longer periods in hospital. He liked to be part of the family group, to play with other children outside, and in particular, enjoyed activities involving cars.

Vision

William's vision appeared normal.

Hearing

There was no evidence of any hearing defect and William commonly eavesdropped and interrupted adult conversation.

Expressive communication

William primarily used eye pointing as his means of communication and to indicate a "yes" response. He had a communication board with 16 choices and 4 colour codes. Although he could use it to express himself, he lacked the motivation to use it as a means of communication on a regular basis. Vocalisation was quite difficult for him. The desire to vocalise could be seen in his body language but it usually took some time for an utterance to be produced. William was good at initiating conversation and he would turn take appropriately during conversations.

Receptive communication

William had good language comprehension according to observations by staff and parents as well as psychological assessments. He would respond appropriately to humorous or sad events in conversation and on TV and became animated if deliberate errors or changes were put into stories. He could identify everyday objects when asked.

Education

William had an understanding of cause and effect and used two switches to access computer games and a slide projector toy. He would often put his foot on the wheel of his buggy and stop it from being pushed. The staff thought that he could solve simple problems but assessing this area was difficult because of his limited function and because he tended to opt out of difficult situations. William was able to discriminate between a few colours and showed an understanding of object permanence.

Physical, life and mobility skills

William displayed an ATNR to both sides, affecting his hand function. He had poor trunk control and sitting balance and was unable to hold his head up for more than a few seconds. William could grasp and release when positioned well but his gross upper limb movement was inaccurate. He had no independent finger movement. He operated his switches either by swinging his arms, or by resting his fisted hands on his tray and using elbow movement to slide on and off the switches. This latter technique gave him better control and accuracy but he could not always achieve a sufficiently relaxed tone to manage the movement. William could roll with minimal assistance. He was toilet trained. He was sometimes difficult to feed.

Initial video interpretation

The pre-intervention school videos show that William was alert and aware of his surroundings but so physically limited that he was unable to effect much control on his environment. His only means of assertion was negative, by opting out of situations and refusing to respond. When interested, he would actively participate in a group although he frequently wanted to be the choice maker in the classroom, volunteering himself regularly.

The initial videos taken at home show William being treated protectively by all his family. William was content to be handled in this way. He nevertheless asserted control over the family and by refusal or by becoming distressed, he usually got his way.

School and home settings

When initially referred to the project, William had recently begun to attend school on a full time basis. He was in a class of children of approximately the same age although possibly less cognitively able. By the time William received his Smart Wheelchair, he had moved into a class of higher functioning children, one of whom he was to share the Smart Wheelchair with (Jack). It was a cluttered environment and the class timetable was heavily structured so chair sessions generally took place outside the classroom in a common hall area used to access all the Junior School classrooms.

William's house was at the top of a steep flight of stairs with consequent access difficulties. Within the house, the living room was large enough for chair practice. The back garden had an easily accessible paved patio area for play.

Aims and aspirations

General education aims

- to assess and expand his knowledge of colours
- to develop the use of a computer for choice making and practice of simple scanning

Communication and socialisation

- to improve social interactions
- to develop eye pointing
- to develop expressive communication through the use of gaze, facial expression and augmentative communication
- to improve functional use of his communication board and extend it by introducing topic or themes
- to encourage vocalisation
- to encourage consistent use of the yes/no response and eye or fist point when choosing
- to assess and develop understanding of simple commands and language comprehension

Physical and life skills

- to improve head control, sitting balance and balance reactions, and to encourage more movement across the midline.

Chair, seating and controls design

William did not have a manual wheelchair or seating system and therefore the Bioengineering Centre at Princess Margaret Rose Hospital in Edinburgh designed and manufactured seating based upon a Britax car seat. A frame was added to accommodate his existing tray containing two light-action, flush-mounted hit switches. William found it easier to access the left tray switch and so it was decided that he would use this to begin chair work with 'Timed' motion tool, no 'Bump' and a forwards only direction.

William's was a shared Smart Wheelchair, the other user being Jack.

Using the Smart Wheelchair

Introduction

The chair was introduced in February 1992. Initially, William was timetabled only for one half hour session in the chair per week. In his first session he sat on his helper's knee, first watching her with the switch and then operating it himself. It was two weeks before he was confident enough to go solo. He immediately had difficulties accessing his switch because his seating position was more upright than he was used to, and he had to stretch to reach the switch. This particular Smart Wheelchair also veered severely and so when William tried to make the chair go forward to move to a particular target, he would veer off to one side and never reach it. The veer was reduced by using higher tolerance components in the Smart Controller, and adding a velocity offset in software to compensate.

Motivation

Following the Easter holiday break there was a gap in use until the beginning of May before he had another opportunity to use his Smart Wheelchair. At this point he did not want to use the chair and seemed to be doing everything possible **not** to operate his switch. It was not clear why he had suddenly lost all enthusiasm: comfort; fatigue; difficulty of switch access; fear; and simple lack of enjoyment were all possible reasons. His seating appeared to be comfortable. Although he did tire quickly, partly because of his general ill-health, he had shown ability to use switches for other purposes for far longer periods than his chair sessions. Confidence and fun were therefore identified as being of most importance. It was not clear whether he was unhappy because he was physically scared, because he disliked the sensation of movement, or he felt pressured by the directive approach taken by some staff. The CALL team suggested that control over steering might give him more enjoyment, but his helper was reluctant to give him the chance (even though he already had good use of both switches to control computer games). Lack of opportunity compounded these problems. William's sessions were timetabled for Mondays and during May several holidays deprived him of access to his Smart Wheelchair. It was June before he had two consecutive Smart Wheelchair sessions.

Steering and Bump and Turn

William's other switch was plugged into the 'turn right' direction control socket in mid-June, but at the same time the 'Bump and Turn Left' tool was selected. The confusion and uncertainty of coping with two interacting system changes occurring simultaneously may have actually reduced William's enjoyment rather than increasing it. 'Bump and Turn' was turned off in favour of 'Bump and Back Off'.

Home use

When William took the chair home for the summer, his parents were encouraged to let him direct the mobility and use chair sessions for fun rather than as learning tasks. If William felt pressured by having two switches, his parents unplugged the turn switch and negotiated steering with him directly. His diary records 20 minute game-playing sessions where he drove the chair and was also pushed around in it.

Small successes

On returning to school in the August, William's interest in using the chair was no better. His Britax seat was removed from the chair and he sat amongst his class in the seat only, to test whether the seating was making him uncomfortable. However, he sat quite happily in this situation. To reduce his anxiety he went back to sitting on his helper's knee while driving and from this progressed back to driving solo. At the same time his helper altered the chair's response from timed to momentary and increased the speed. Thereafter William showed his first signs of actually enjoying a Smart Wheelchair session.

Classroom use

Shortly after this, his teacher agreed that he could bring the chair into the classroom for a tuckshop library session. William used his mobility to approach staff and then used eye pointing to choose books.

Continuity

There had possibly been some deterioration in William's physical skills since the summer holidays and he had difficulty accessing both switches. He went back to using one switch only with 'Bump and Turn' to provide some steering. In October 1992 William's helper left, was not replaced and frequency of chair sessions decreased. William was off school with illness from February 1993 until the end of April and there was a marked deterioration in his physical skills on his return to school.

New staff

A new key person who was enthusiastic about the Smart Wheelchair was appointed while he was absent. When he returned, he was very motivated to use the chair more frequently within the classroom and around the school building. He was still using a single switch and 'Bump and Turn', and seemed happy to negotiate with helpers when he wanted them to turn him. His illness had reduced his stamina for long chair sessions and reintroducing a means of steering was delayed until he became stronger.

Post-study Profile

Personality and cognitive state

The class team report that William definitely seems to have matured in the last year and has developed into quite a patient yet persistent boy. If something on his chair is not working, he keeps trying with it while somebody fixes it. The class team also feel he is more tolerant and motivated to participate in classroom activities and activities at home. He likes taking part in group sessions, whereas pre-intervention he was more comfortable in one-to-one situations. He seems to enjoy using his Smart Wheelchair around the classroom and combines his mobility with use of an ORAC voice output communication aid.

Vision

William makes good use of eye pointing when choosing drinks or children from a circle. The class team also feel that he knows his colours well.

Hearing

There seems to be no change in William's hearing.

Expressive communication

William still lacks motivation to use his communication board. It is restrictive when communicating with the other children in the class and he prefers eye pointing in these situations. He is keen to use an ORAC communication aid, accessed by hand, and the classroom team are hoping this will be a method of communication for the future.

Receptive communication

There seems to be no changes to William's receptive communication.

Education

William uses the computer more in classroom activities. He is limited by his accessing. The class team report that he can identify sets and shows basic number skills. The class team think that he can count. Both school staff and his mother think that he can count but because of his lack of physical ability, this is hard to judge.

Physical/mobility skills

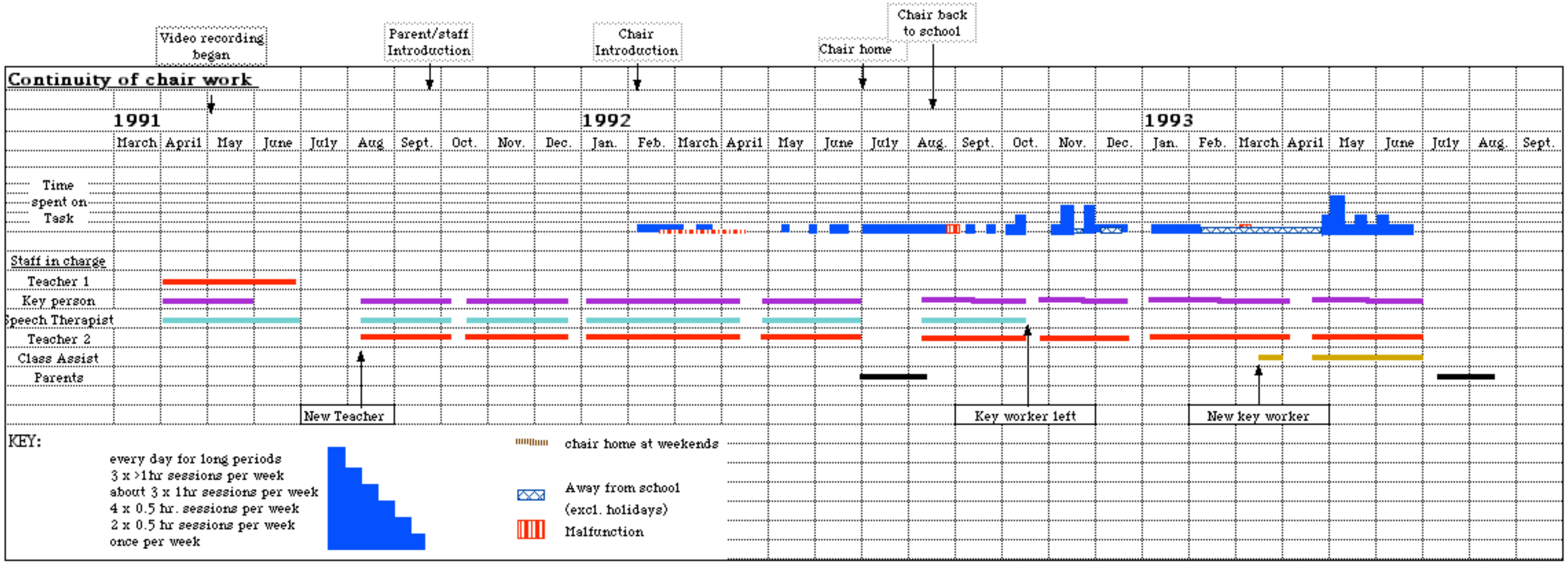
His motor skills seem to have improved but this is hard to assess given his weakness due to illness. His mother thinks that his head and upper limb control is stronger and has improved, but the class team do not agree. The class team feel that he has limited independent mobility using the Smart Wheelchair but can not be regarded as functionally mobile.

Long term process measurements

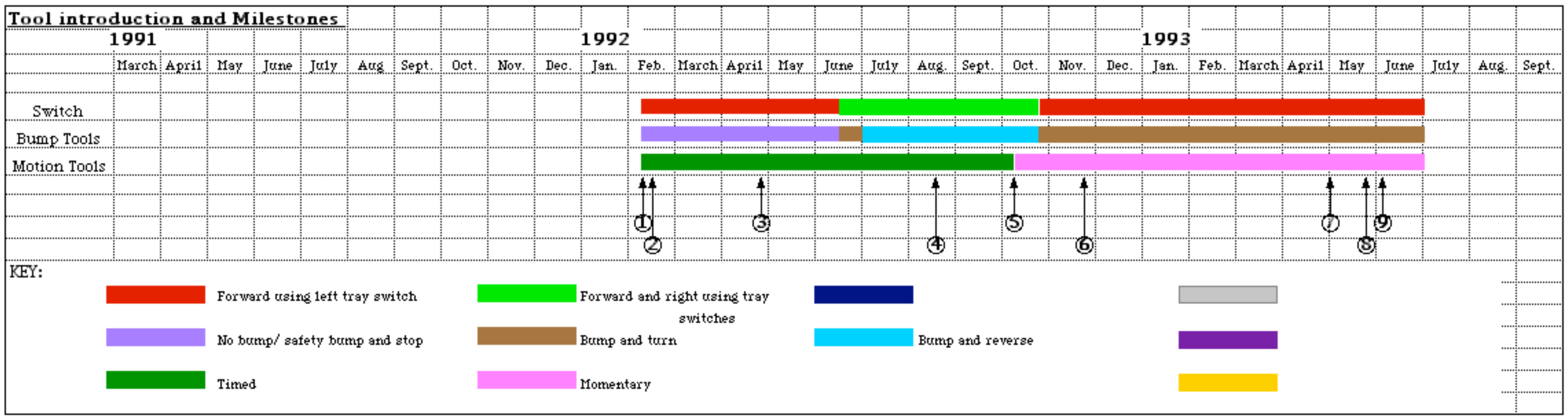
William's Continuity Chart shows that he had minimal amounts of practice which were further interrupted by periods of illness. The Tools and Milestones Chart show the consequences of this lack of time on task, by the very small number of milestones, the small changes in tools, and the regression from two switches back to one. Despite these problems, it is evident from the Post-profile observations that some aspects of his abilities have improved, although it is very possible that these improvements have been caused by maturation more than through use of the Smart Wheelchair.

William's attainment of functional mobility skills has been disappointing since he has the physical and cognitive skills to achieve more. However, he was disadvantaged by illness and consequent lack of practice and, health permitting, he will continue to use the chair and hopefully develop greater control over it using a larger number of switches, or a scanner.

William



Video recording began
Parent/staff Introduction
Chair Introduction
Chair home
Chair back to school
Continuity of chair work
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Time spent on Task
Staff in charge
Teacher 1
Key person
Speech Therapist
Teacher 2
Class Assist
Parents
New Teacher
Key worker left
New key worker
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school
(excl. holidays)
Malfunction



Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Switch
Bump Tools
Motion Tools
1 2 3 4 5 6 7 8 9
KEY:
Forward using left tray switch
Forward and right using tray switches
No bump/ safety bump and stop
Bump and turn
Bump and reverse
Timed
Momentary

****Replace before binding****

Progress Chart (blank side, should be even page number)

KEY TO MILESTONES

1. William sits on his helper’s knee using his own switch. He eye points to go into another classroom, then outside.
2. He has switch accessing problems when solo, but is trying very hard.
3. He is doing everything possible not to operate the switch.
4. "A decision is taken to remove the seat from the Smart chair and to have William sitting in a seat among the class to help him become used to it in a ‘low profile’ manner."
   He is happy just sitting in the chair
5. "The speed is increased and the system altered to momentary as a previous session that day seems to justify this. This is very successful. William smiles when he discovers that if he keeps his right hand on the switch, he keeps turning in circles."
6. "William moves his chair and begins to eye point to the tape on the table. M., pretending not to understand, shows him various books nearby and gets a 'no' response. Eventually she picks up the tape and they have a chat. He then begins to move his chair forward and to eye point to the working surface at the back of the class (where the tape recorder is usually kept) and to the tape lying on his tray. M. asks him if he is looking for the tape recorder and he indicates that he is. It is explained that J. is using it and it can’t be taken away from him. When asked if he wants to be turned round to have a look at another book, he again gives a ‘yes’ response and moves himself forward to eye point to another book on the table."
7. "William is looking around all the while at the table when he is going to the library. C. asks him if he would like to look at his book. He then, with some steering help from R., drives round to the tuck shop. William is participative and intent on what is happening at the tuck shop and keen to drive off and put his sweets in his bag to go home."
   "He attends assembly in the front hall and, when congratulated for doing so well, he does a circuit of the hall to let everyone see how well he can manage. He waits in the hall until everyone has returned to classes, then he comes back to the classroom on his own."
8. "William is left in the front hall and comes into the classroom for shop and library. He then has to leave the classroom to find me. I had gone to collect some bibs. He finds me in double quick time."
9. "William is determined to get a new symbol for his symbol board from A. He doesn’t trust her to come back with it so goes up to the Senior School to look for her and pick it up from her himself."

4.4 Group 3: Reducing Passivity, Encouraging Socialisation and Interaction, Promoting Exploration and Play

4.4.1 Sara

Introduction

Sara was seven and a half years old when she was referred to the Smart Wheelchair project in November, 1991. The second of three children (her parents having recently had another child), she had previously attended an Early Education Centre and Nursery and was now in the Junior School of a grant aided special school. By the time chair work started, she had moved to the Senior School. This was an appropriate placement for Sara as she is a child with cerebral palsy and a spastic quadriplegia. She was described by those who knew her as a bright and happy girl who appeared to be hearing but whose vision and visual range was difficult to assess. She had a consistent yes/no response, but found vocalisation extremely difficult and was not yet using eye pointing in a functional manner.

Sara's parents were particularly supportive of the project and were keen to have the chair home. Her father felt that her family had exhausted all other games and toys available for Sara and was keen to exploit the Smart Wheelchair as another means of play for her.

Pre-project Profile

Sociability, personality and cognitive ability

Sara was described as a generally happy child though she appeared to have some days of depression when she would sit unsmiling for no particular reason. She was aware of her environment, and held sometimes quite strong opinions: for example, she liked new clothes and had a strong dislike for soft toys and animals. Sara was described as being easily distracted, particularly by noise in another area of the classroom. She tended to be wary of an unfamiliar adult and on some occasions showed a clash of personality with others. In the main, she very much liked to be included in the daily happenings at home and in school.

Vision

Sara's vision and visual range were difficult to assess. She would glance fleetingly at objects or people and appeared to have difficulty in locating a communicant. Staff noted a tendency to prefer auditory rewards in cause and effect activities rather than visual ones. However, Sara did show some visual abilities. She had established object permanence and would look for a hidden toy, and responded appropriately to visual stimuli (so that if a biscuit were silently presented to her, she would open her mouth).

Hearing

There appeared to be no evidence of a hearing defect.

Expressive communication

Sara interacted well with familiar, well-liked adults. She had a consistent hands up to communicate 'yes' and a tongue out signal for 'no'. She found eye contact difficult: eye pointing was also very dependent on her seating position and was therefore not reliable. Choices always had to be backed up with a yes/no check. Sara had difficulty vocalising and found it difficult to instigate or control vocalisation though she succeeded better when she was relaxed. Staff felt that this vocalisation problem was due to a dyspraxic element.

Receptive communication

Sara appeared to understand a fairly wide range of words, especially to do with concrete situation.

Education

Sara was described as being easily distracted. She would tend to tune into other noises at the other end of the classroom.

Mobility and physical skills

Sara had difficulty controlling any part of her body. She had great problems with her head and tended to go into an extension thrust pattern. One effect was the influence of this pattern over her means of communication - on occasion, the involuntary movement was triggered when she was asked for an arm up for 'yes', therefore precluding her from responding. She tended not to have control over hand movement at all. Sara could roll from her back to her front but was not able to roll over or use such rolling as a means of mobility.

Initial video interpretation

Pre-intervention school videos show Sara as a child who seemed alert and interested in what was going on in her surroundings. She made very definite choices of yes and no and did seem to respond better to certain individuals in the classroom than others. Equally the first videos taken at home show again Sara's interest in her surroundings and her willingness to communicate with her parents.

School and home settings

Sara's school is run by the Scottish Council for Spastics. During the project, her team remained reasonably stable, with the exception of one change of teacher (who moved to another class within the same school).

The classroom had few clear spaces, but was quite large. There was a flexibly interpreted daily timetable, within which the teacher and other staff could make changes in response to emerging needs. The school itself is in a large old Victorian building with narrow corridors. It has no large uncluttered area in which chair work could take place without disturbances.

Sara's family lived in a small house, but despite this her parents were very willing to have the chair home. It therefore went with her on most major holidays. Her father was also keen on taking Sara out in the chair to visit a friend and this she did on a number of occasions.

Aims and aspirations

At the outset of the project, the team's stated aims were quite general, with a strong emphasis on mobility, play and exploration, and transferable control skills. Sara's team were also keen to emphasise careful monitoring of potential detrimental effects, such as might come from overuse, or over-constrained positioning in use:

- continued development of switch skills, and transfer of these to environmental control and participation in games
- to encourage choice making
- to provide opportunities to mix with other children beyond her class peer group
- to encourage exploitation of her yes/no response
- to encourage turn taking in group communication and play
- to contribute to continued development of language through stories, song and outings
- to maintain range of joint movement
- to ensure correct seating at all times and to encourage voluntary movements and control of involuntary ones.

Chair, seating and controls design

Sara had already had a specialised seating insert made for her manual wheelchair. The Princess Margaret Rose Hospital team therefore built a frame on to which it could be transferred to her Smart Wheelchair. This also enabled a standard wheelchair tray to be added to the Smart Wheelchair at a later date.

Prior to the project, Sara had been using an arm raise switch devised by the Princess Margaret Rose Hospital for computer work and access to toys. It was decided to continue with this particular switch when starting with the Smart Wheelchair and it was set up with 'Bump and Stop' tool and a 'Timed' motion tool for forwards direction only.

Using the Smart Wheelchair

Sara began the Smart Wheelchair work sitting on the knee of her helper and quickly progressed to driving the chair solo. Despite an initial, very long session that really was quite demanding, Sara remained attentive throughout and seemed to enjoy it.

However, the initial choice of switch was soon found to be inappropriate in a dynamic environment. If the chair bumpe during these early sessions, her resulting uncontrolled arm raise would activate the switch. This was also a problem when speaking to Sara whilst she was driving the chair: her 'yes' response also activated chair movement. Another means of accessing had to be quickly devised.

It was decided to try a hit switch mounted directly onto a tray. Despite the fact that Sara had difficulty targeting, she succeeded in using this switch to drive her Smart Wheelchair. At the time she was using her right hand to activate the switch as this was thought to be her better hand: her left hand was gaitered in the belief that this constraint would help her avoid unwanted movements, and thus increase the control she had over her right. Fortunately for our observation of her abilities, during one early session her left arm was left unconstrained: her head control remained very good, and she was seen to try to use her left arm to operate the switch.

This brought the project up to Sara's summer holidays, and Sara took her Smart Wheelchair home for that period. Her parents continued experimenting with control setups, including leaving the gaiter off her left arm. Her mother recorded that her head control was good and she was quick to use her switch with no long gaps between activations. She was mainly using her right hand but on occasion she did use her left.

The introduction of the 'Bump and Turn' collision tool just before the summer holidays resulted in Sara looking behind her in response to the upcoming, chair-controlled turn after a collision. She seemed to be paying great attention to what was going on both in front of her and behind her and she would anticipate turning to the left as her chair turned her out of the way of an obstacle.

By the time Sara returned to school in the August, the staff were pleased to see how much she was now using her left hand on the switch. Up to now, Sara had relied on 'Timed' control, since we were unsure of her ability to release a control after an activation. The team decided that they would like to try Sara on momentary control (which needs a lot more skill, including timing, and the physical ability to release on demand). Sara clearly knew what was required, and tried but at first was not able to stop on demand. Within a week, she was using momentary appropriately and well. Some comments on appropriateness are needed. Sara (like other children) did not necessarily immediately use her new skills to drive in ways which would pass a driving test. She liked to bump into objects or walls, partly to try out the limits of her skills, and partly to make her mark on people and surroundings. This is appropriate play behaviour, but not, perhaps, what a vehicle centre might look for when prescribing a wheelchair.

At the beginning of October, Sara was admitted to hospital for an operation and came back to school in plaster from her toes to her armpits. The team were keen that she should not have a break in her Smart Wheelchair work longer than necessary and they set up a wedge on her Smart Chair enabling her to lie prone, yet still operate her hit switch (which was temporarily positioned on the foot plates). Sara was not keen at first to lie in such a position, but she tried. Her face lit up when she hit the switch and managed to make the chair move.

By January 1993, Sara was generally more alert. The staff felt her head control was better when using the chair and since she was managing to control turns well enough to stop in time to face the desired object, choice exercises were being built around this skill.

Sara's system had a right turn control added at the beginning of February 1993. Right was chosen first since she seemed to have finer control over her right arm and we wanted to provide early successes wherever possible. About that time, too, the staff were also trying to encourage Sara's use of the ORAC augmentative communication aid, and she would go on expeditions with her Smart Wheelchair with the ORAC sitting on the back. Her teacher and therapist tended to use her right hand for ORAC work, unplugging her from the wheelchair's right turn control as the need arose. Discussions were started about how to integrate the two systems more closely, and when she might be cognitively able to deal with such changes.

Reports in the March suggested that Sara was using both switches well. She was looking round and stopping appropriately at times and seemed to be really pleased with her success. However, from about the beginning of May, something was going wrong: Sara was having great difficulty accessing her switches. She also appeared to be having difficulty stopping when approaching a wall or a passing doorway and this difficulty continued on until the end of term. At the end of the project, it was unclear if this was a learning plateau, or if there was a more fundamental problem.

Post-study Profile

Sociability, personality and cognitive ability

By the end of the project, Sara still didn't relate to her school peer group, and still made no real effort to communicate with them. However, her mother reported that she seemed to like the children at home better (although she still hated small children and toddlers coming near her). She also revealed herself to be a child who didn't much like change (an example of this being her initial negative reaction to the addition of the wedge on the chair).

Sara was now judged to be quite persistent, and school staff felt that she persevered well with her controls even through extended and frustrating failure, until she succeeded.

However, through all her trips in the Smart Wheelchair, the staff did not feel there were any signs of exploratory behaviour. Sara was not a child who looked around her when she reached her destination. On the other hand, they did feel that she was able to show assertiveness.

Vision

Much more evidence had emerged about Sara's vision. Her use of the chair showed adequate functional abilities for mobility purposes, and this was now being supported by her work in picture selection, where she was reported to be quite good both at choosing from drawings and from photographs. She was also eye pointing to the E-Tran frame and was able to choose effectively out of three or four options. She still had some difficulty making eye contact or fixing with her eyes but had been observed tracking people intermittently.

Expressive communication

Sara's improved eye pointing, particularly in a more controlled situation, had definitely helped her communication. It was felt that she was still easily distracted in the classroom and therefore was not as successful in using eye pointing as a means of communication there. The team recognised a strong element of dyspraxia affecting Sara when she was attempting to vocalise. As a result she had difficulty in initiating conversation with peers or adults. Gains in midline posture had actually had some detrimental effects on her 'yes' response: because her head was better placed in the midline, further head up movement tended to trigger extensor thrust.

Receptive communication

The staff were still very unsure about Sara's comprehension. There were some times when they thought she was really understanding what was being said to her but at other times there seemed to be no understanding or response at all.

Physical mobility skills

Sara's head control had improved considerably. She did not tend to go into extensor patterns so much and could be easily persuaded out of them, especially when she was able to maintain her head in the midline position. In addition, staff considered that her balance had also improved. She is also now able to target her right hand on to a switch and (less consistently) her left: as yet there is no other change in her hand function. Both Sara's parents and the class team felt that although she enjoyed her Smart Wheelchair sessions, she still had no clear idea of its functional usefulness to her.

Goals achieved

By the end of the project, the team felt that the work had contributed directly to the following goals:

- continued development of switch skills, and transfer of these to environmental control and participation in games
- encouraging choice making
- maintaining range of joint movement
- ensuring correct seating at all times and encouraging voluntary movements and control of involuntary ones.

The team also feel that the environmental opportunities opened up by chair work helped

- to contribute to continued development of language through stories, song and (particularly) outings
- to encourage exploitation of her yes/no response.

Although the chair

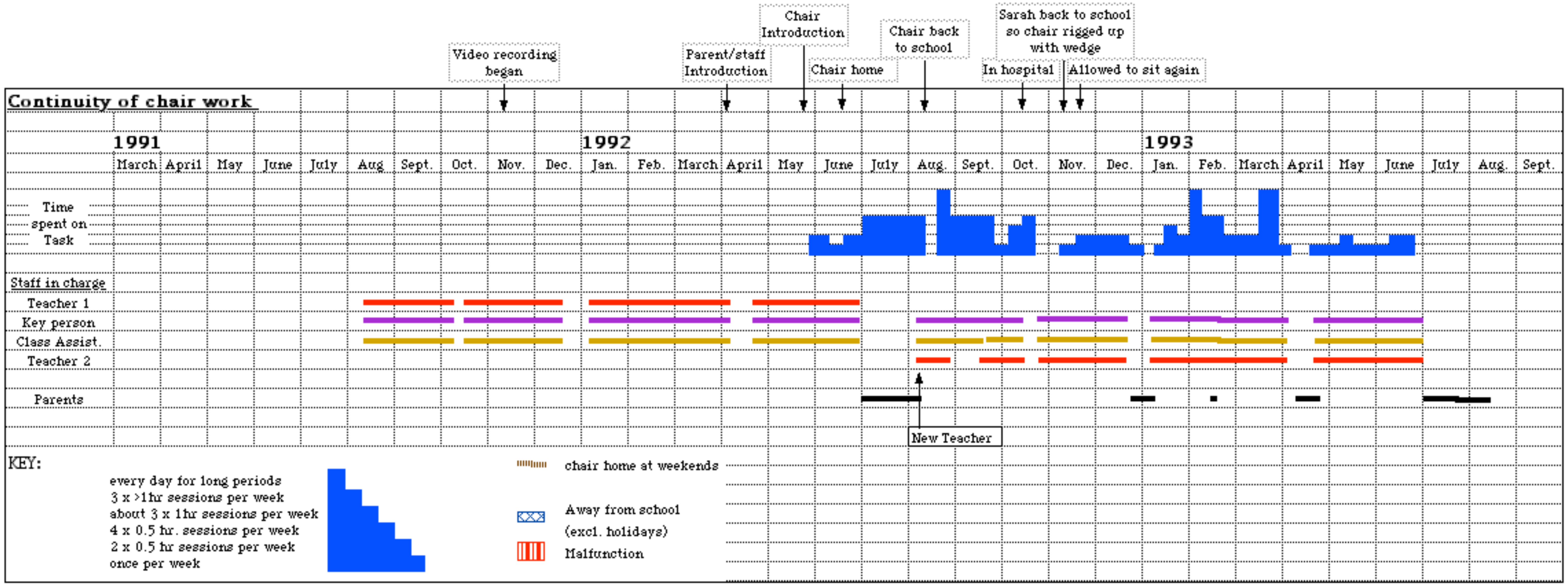
- provides opportunities to mix with other children beyond her class peer group, and
- encourages turn taking in group communication and play,

Sara has not yet started to make use of those opportunities,and more encouragement is needed for this and other autonomous activity.

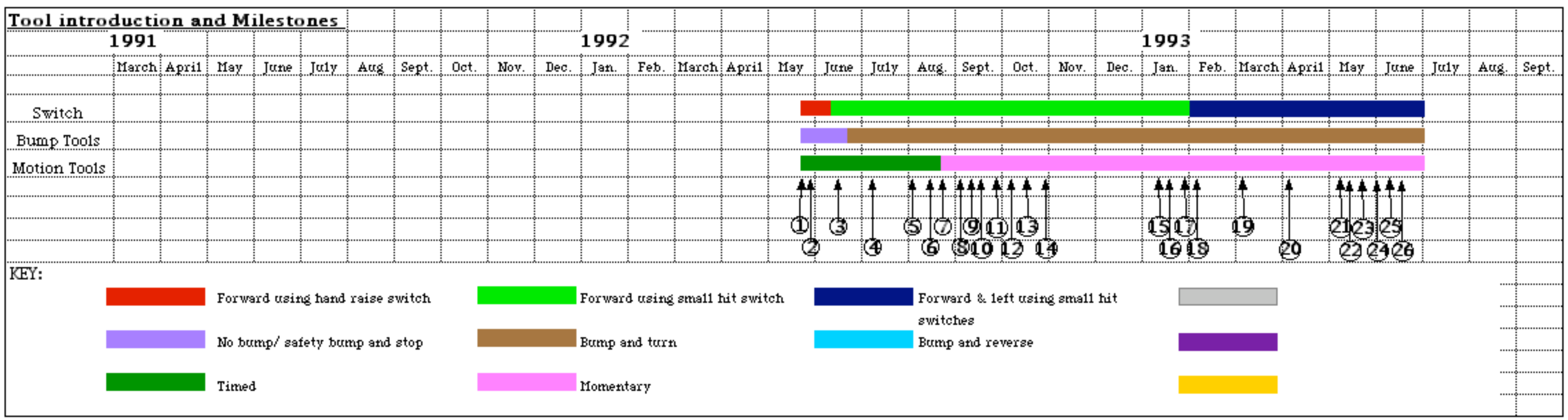
Throughout Sara's time in the Smart Wheelchair, the team felt that the dyspraxic element which she displayed when trying to vocalise probably also manifested itself in her control of her switches. She was much better being left to operate the switches by herself, being given no instruction. The moment someone stood over her and told her what to do, she had problems organising herself.

It is very difficult to set up situations where a child is simultaneously given both high levels of structural support and personal freedom, especially where the natural inclination of a teacher or therapist is to intervene and guide. In some early sessions (again as with other children and their teachers and therapists), staff tended to intervene more than later in the project. Less intervention proved more effective. In early sessions, for example, much effort went into direct training in stopping on demand, and in maintaining head position. These skills proved very difficult to acquire because of Sara's dyspraxic reaction and the effect it had on her arm control and general positioning. In later sessions, where her helper was less directive, Sara proved herself able to organise her movements, given time. Once directiveness was reduced, a definite improvement in Sara's head control was noticed and it continued to improve over the following months of the project.

Sarah



Video recording began
Parent/staff Introduction
Chair Introduction
Chair home
Chair back to school
In hospital
Sarah back to school so chair rigged up with wedge
Allowed to sit again
Continuity of chair work
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Time spent on Task
Staff in charge
Teacher 1
Key person
Class Assist.
Teacher 2
Parents
New Teacher
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school (excl. holidays)
Malfunction



Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Switch
Bump Tools
Motion Tools
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
KEY:
Forward using hand raise switch
Forward using small hit switch
Forward & left using small hit switches
No bump/ safety bump and stop
Bump and turn
Bump and reverse
Timed
Momentary

****Replace before binding****

Progress Chart (blank side, should be even page number)

KEY TO MILESTONES

1. Sara understands cause and effect.
2. Sara goes solo for a long session that is quite demanding. She is attentive throughout and seems to enjoy it.

3. Sara chooses to drive down to another classroom, but will go no further than just inside the door and answers 'no' when invited into the room. Her arm has not been gaitered, but her head control is very good and she attempts to use her left arm to operate the switch.
4. "Her head control is good and she is quick to use the switch with no long gaps. She mainly uses her right hand, but occasionally uses the left. She looks behind when backing out, paying great attention in front and behind. She looks a lot to the left in anticipation of turning left."
5. "She uses the chair at the same time as the electric organ, using her right hand for switch and left for keyboard. She is alert and sitting up straight."
6. She uses her left hand on the switch, but is not able to stop to command.
7. After initially being 'on strike' or distracted, she is using momentary appropriately and well within a week.

8. "She is trying to use her left hand on the switch which is positioned on the right of the tray."
9. "She likes to bump into objects, walls or even people, but does not like being bumped into herself."
10. "She is keeping her momentary switch down for long periods at a time, and is still not stopping by intention. She is also turning to the right in a full circle using the switch. She enjoys this game and enjoys twirling round and round in circles."
11. Sara chooses to drive to the swimming pool with her helper steering. "She manages it with 4 presses on the switch, then decides to wander here and there, looking at all the staff's cars (stopping and having a little chat about them)."
12. She appears to be more interested in what is going on around her, and enjoys wandering. She likes to do the more mundane but necessary chores like going to the toilet.
13. She is not keen to lie on the wedge, but her face lights up when she hits the switch and makes the chair move.

14. "The first time that Sara has been in the chair in the sitting position. She doesn't move about much, but is being nosy and seems to want to look around more."
15. Sara manages to get to the pool with a little help with the steering and seems to really enjoy being back in the chair. Her head is up and she is looking around.
16. Sara generally more alert, with better head control. She is using the chair in turn and managing to stop in order to face an object she chooses.
    In speech therapy session, she is being encouraged to turn to find a person's bag, using her left hand on the switch in turn. She has to select whose bag to turn to next using a picture book. She is stopping well and appropriately, and looks to be trying to shake her head for 'no'."
17. "Sara wants to play the treasure hunt game, and will tell me which direction to go by looking at the coloured squares. She needs help with direction but is still looking around well."
18. "I take away the right hand switch to allow her to concentrate on the left and this seems successful. Her stopping at appropriate times is also good today. She took the ingredients from the big table to the little table, having to use both hands for the switching."
    "We play 'What's the time Mr. Wolf?' Sara enjoys sneaking up to the wolf and also turning away, but isn't so keen on the turning."
19. "She really uses both switches well. She is looking around and stopping at appropriate times. Sara is really pleased with herself,and knows how clever she's been."
20. "She doesn't use the left hand left turn switch much, but is quite keen to get to S's and is hitting the switch quite purposefully and is quite proud of herself on arrival."
21. "Sara has great difficulty accessing switches today. Her arms are very tight. The right arm comes forward and swipes over and off the switch without enough pressure to activate it. Her left arm being gaitered does not appear to improve ability; when placed on with help, she then cannot remove it."22. "She attempts to go along one long stretch down the corridor. I deliberately do not stand close and encourage her all the time, but leave her alone to get on with it. There is no evidence of any attempt to stop when approaching a wall or when passing the doorway to the shop."
23. "Her right hand activates the switch for longer periods which allows her to progress at one stage about 10 feet. She makes little use of the left switch."

24. "Her right switch use is much better today once she gets into it. She again has initiation problems, but by the end of the session, she keeps the switch on from the back to outside J's class. Her head is in a good position during this spell, with her right hand occasionally coming across to operate left switch."
25. "She shows great difficulty in stopping appropriately, either before crashing into walls, doors, people or to stop beside someone. Her hands are at times lying at rest across the midline and occasionally a switch will be activated by the opposite hand."
26. "Her right hand is initiating well and sometimes she is able to maintain this for up to 8 seconds. Her left hand is much tighter and is not operated spontaneously."

4.4.2 Ross

Introduction

Ross was chosen for the Smart Wheelchair project in April, 1991, but was low on the delivery schedule, and work began with him in May 1992. At the time the initial profile was drawn up for Ross, he was 13 years of age. He has a spastic diplegia and moderate learning difficulty. Ross was able to walk using a rollator and could propel a manual wheelchair for short distances. He is one of three children in a family who were keen that he should participate in the Smart Wheelchair project, but were not keen to have the chair home.

Ross attends a special school for children with moderate, severe, and multiple disabilities. When Ross was first introduced to the CALL team, he was a member of a mobile class group but moved classroom in the intervening period before beginning chair work to a class where he was the only mobile person. Both class teams contributed to his pre-study profile. Just prior to chair work beginning, he moved class yet again, to be among pupils who were more mobile.

Pre-project Profile

Ross was described as a very sociable boy who enjoyed the company of other children and adults. He was a quite mischievous and affectionate young man given to testing the tolerance of new members of staff by swearing or minor misbehaviour. Ross demonstrated good short and long term memory, learning new tasks quickly and anticipating the daily classroom routines.

He showed a very determined nature, and desperately wanted to be physically independent. Walking was a physically difficult and strenuous task for him and yet he persisted with it and would frequently refuse help. He demonstrated a good attention span although he would frequently opt out of situations in which he did not want to anticipate.

Vision
Ross had good vision.

Hearing
There was no evidence that Ross had any hearing difficulty.

Expressive communication
Ross would usually communicate through a mixture of Makaton signs, gesticulation and some spoken words, letting his needs be known through gesture, vocalisation, eye pointing and getting up and going for it. We noted that he used a lot more words at home than he did in the school settings in which we worked with him. He initiated communication with adults only, and didn't attempt to communicate with his peer group.

Receptive communication
Ross typically understood one key idea in a spoken sentence during testing, but seemed to be functionally better in day to day communication, making good use of everyday objects and words and responding appropriately to other people's facial expression and tone of voice.

Education
Ross was able to match pictures of objects and was felt to have a limited understanding of cause and effect when using picture matching and picture building on a computer touch screen. His mobility showed him able to deal with spatial problems, and plan paths properly, pushing objects out of his way when necessary or altering his route.

Physical skills and mobility
Ross was described as having good eye/hand coordination. He was able to do jigsaw puzzles, setting the pieces the correct way round. He could crawl, and walk with the aid of a rollator as well as manoeuvre a manual wheelchair to a limited extent. He appears to have strong upper limbs and is keen to be independently mobile.

Initial Video Interpretation

The pre-intervention school videos confirm Ross to be a child as described in his pre-project profiles frequently interacting with adults but less frequently with his peer group. He showed himself to be quite assertive and capable of communicating his needs and desires.

The initial video taken at home shows him to be even more assertive, demanding attention on a fairly constant basis.

School and Home Settings

The environment in which the chair work took place was a small, fairly constrained classroom, but the staff also had access to a large shared area and in addition were able to use the school gym on occasions.

Ross's mother indicated at the outset of the project that she was not keen to have the chair at home, so that all work took place in his school.

Aims and Aspirations

Ross was not chosen primarily for investigation of mobility-related issues. As the profile shows, he already showed good strategies in that area which were well under development. Instead, we hoped to use his Smart Wheelchair experiences to extend his learning environment, and to give school staff the opportunity to set up tasks which would allow observation of emergent skills. (Of course, this still involved using the chair initially as a motivational aid centred on mobility: had Ross found the chair functionally useful as a mobility aid, we would have increased the priority of those aspects. However, the long-term goal was to have him use the chair for more formal learning tasks). The curriculum aims set out for Ross by his class teams were as follows: as with other children, we have included non-project related goals where they seem relevant.

General educational aims

- to recognise written names
- to increase concentration span
- to encourage concrete, constructional play
- to encourage symbolic play and simple pretend play
- to improve copying, matching

Communication and socialisation

- to further his communication skills
- to further develop vocalisation and encourage the use of appropriate single and multiple words (as part of a multi-modal communication strategy with signing)
- to improve Makaton signing
- to improve comprehension
- to encourage imitation of motor or oral communication

Functional mobility

- to encourage independence within his physical limitations
- more independence in walking

Physical skills

- to improve body image
- to improve hand/eye coordination, i.e. pencils skills
- to improve fine motor skills, i.e. manual skills and precise grips
- to improve righting reactions and sitting balance and improve transfers.

Specific early aims and activities for the Smart Wheelchair were:

- developing mobility related Makaton vocabulary and use
- ‘go and retrieve’ activities
- unaided exploration
- to be able to carry school task related items from room to room
- ‘colour corners’, i.e. locating things
- collect items matching.

However, in our discussions with the first staff team, we made it clear that these early aims were seen as stepping stones to later, more complex work. Ross was thought to have particular difficulties in symbolic understanding and planning and when chosen for the project he was seen as a pupil who might benefit from using the Smart Wheelchair as a sit-on-Turtle, i.e. using LOGO style commands using symbolic representations for route planning. We hoped that the chair should encourage new educational programmes, perhaps based on early learning work developed by other researchers.

Chair, seating and controls design

Ross did not use modified seating in his manual wheelchair, but needed it for the Smart Wheelchair. A seating system was constructed from scratch by the Princess Margaret Rose hospital Bioengineering team. This was a difficult task because Ross was considerably taller than the majority of the children on the project, and had big feet. The combination can be awkward if the rider is not to project forward of the collision sensor assembly.

His seating was therefore fixed high off the chassis. Because he had good hand function, it was decided that Ross would be able to cope with a switched joystick on the right hand side. Ross’s family pointed out that he had tried to use a joystick supplied with computer games and didn’t really have much idea how it worked. We therefore arranged that his joystick would be gated for forward direction only in the initial stages. It was thought that he would start with the ‘Timed’ tool until he had established cause and effect and the chair provided ‘Bump and Stop’ services.

Using the Smart Wheelchair

Smart Wheelchair work began in May 1992. The initial stages were disrupted by his having both to move class and start chair work about the same time. Staff in the new classroom were unfamiliar with the wheelchair project. The change of classroom immediately prior to chair work meant that further training had to be provided as the new classroom staff were not familiar with the Smart Wheelchair project, or aims that had been suggested when Ross was referred. We hoped that we had stressed sufficiently that Ross had not simply been supplied with a powered wheelchair for mobility purposes only.

Ross, like the other children, began Smart Wheelchair work sitting up on the knee of the helper (although this exercise was short lived, it being clear that Ross would be capable of sitting alone and had no fear of the Smart Wheelchair). By the middle of June, Ross had mastered the forward control, and it was obvious that he wanted to change direction. His video showed him moving forward relentlessly, while pointing in another direction to where he actually wanted to go.

The team decided to add another gate to the joystick to allow him to turn right. At the same time, he was offered ‘Bump and Turn’ collision response to the left. The class team were reluctant to move from timed to momentary and so Ross continued using the timed motion tool.

Despite demonstration and co-control work (with his helper moving his hand, Ross couldn’t work out how to use this new degree of joystick freedom to achieve a right turn). He would still drive in a forward direction and point to be turned, and didn’t seem to be able to understand that he could change direction himself. Unfortunately, precisely at the time when he should have been able to practice and explore unhindered, there now followed a series of interruptions which made progress very difficult.

Firstly, his efforts weren’t helped by one of the Smart Wheelchair’s rare failures - he became the victim of a rogue fault during July which would not go away, adding to his confusion. The complete chassis was replaced at the end of July.

Next, despite the fact that Ross attends a 52 week school, when his class teacher left at the end of June for her summer break chair work ceased until the middle of September. Ross had made no progress in his understanding of turn and being able to move forwards by the middle of October.

In October, the team surmised that the mixed chair / user controls were just too confusing, and that a simpler new approach might be appropriate. He was given a right, left and forward gated joystick and his bump tools were switched on to Bump and Back Off. At the same time, the staff accepted that momentary control might now be appropriate. This timing modality appeared to be a lot better for Ross, although he still did not show any real understanding that using the joystick in a right or left direction controlled the rotation of the chair.

These experiments focussed attention on Ross's understanding of abstract concepts, and showed that much more work was needed on these. At that time, the project team were increasingly concerned that direct mobility exercises were not the route to these issues, and that we would have preferred to construct more symbolic routes. However, a second distraction now loomed.

Unfortunately, at this time, Ross was admitted to hospital for a large orthopaedic operation and did not appear to be in school from October until the end of December. In the early part of January, Ross came back to school and, despite his being in plaster, the CALL team tried to see whether he could be got back into his Smart Wheelchair. Sadly, because his legs were too long it was not a safe option.

Once Ross was out of plaster, the Smart Wheelchair team decided to try encouraging his understanding of directional control by separating the directional functions into distinct controls (possibly using symbolic labels). This is a technique which had proved quite useful in another setting, and which they hoped might contribute to Ross's other choice work using his IntroTalker. We set up two QED hit switches for left and right control, restricting his joystick to forward only. Unfortunately, the system was never really put to the test: chair work did not resume despite encouragement from the CALL team. It was used approximately seven times between January and June of 1993.

Post-project Profile

Personality and cognitive state

There were times when Ross showed frustration with the Smart Wheelchair. Teachers on the team felt that he could walk more and he was able to use his manual wheelchair better than his Smart Wheelchair, and described situations when he often didn't want to go into it at all. Similarly his therapists described his frustration with the Smart Wheelchair but felt that it wasn't used to its full capacity and therefore he was frustrated by its limitations. The classroom staff also felt that Ross was not cognitively stimulated in the wheelchair.

Expressive communication

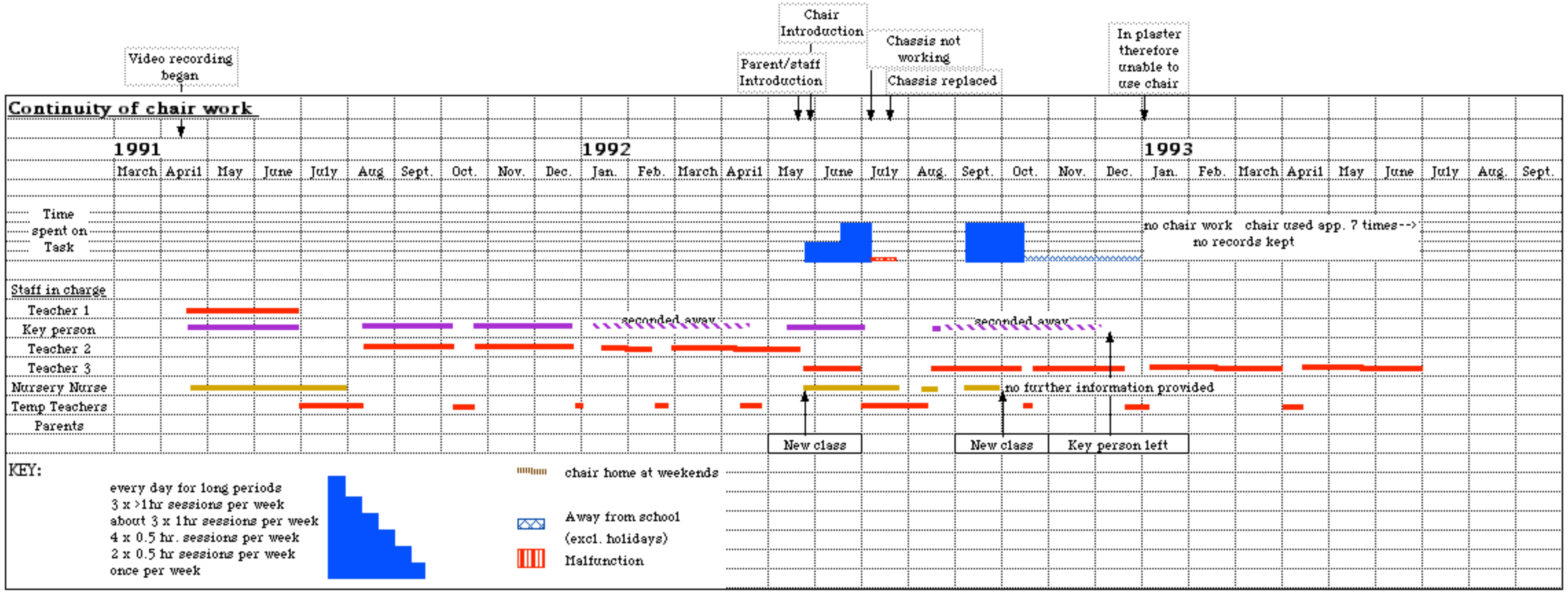
Ross had quite recently begun to use the IntroTalker and was interested and used it well in certain situations. He was also using a lot more Makaton signs as part of his communicative repertoire.

Physical mobility skills

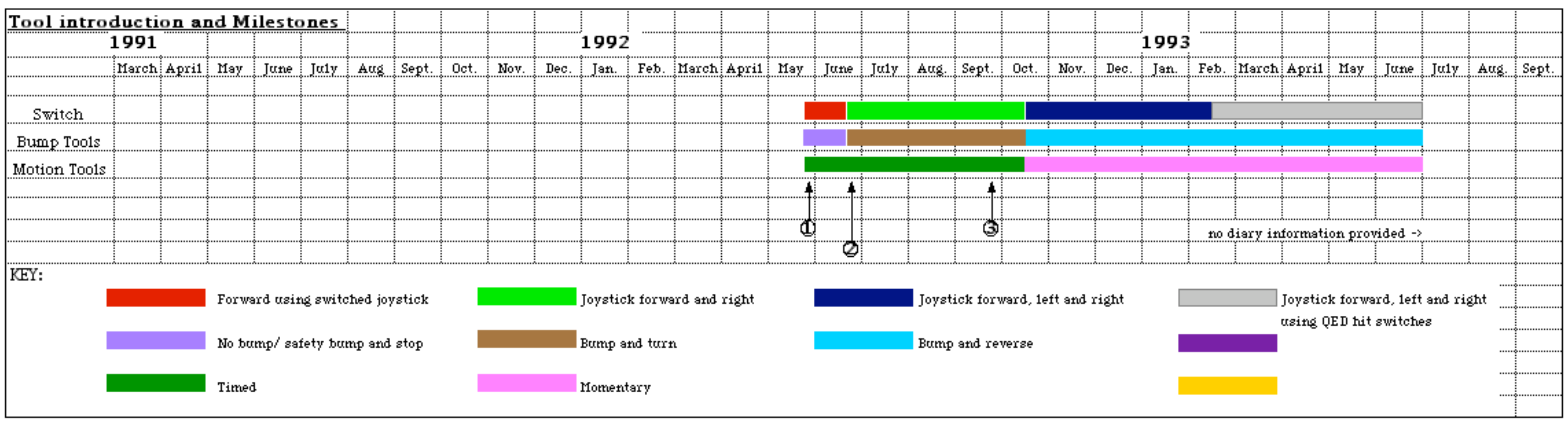
Ross's walking had improved after his surgery and again he showed a wish to be independently mobile. The class team commented that, when left to himself, Ross could be very mobile in the Smart Wheelchair and could drive himself anywhere but tended not to like to do it for an audience. Ross, by the end of the Smart Wheelchair project, remained a friendly, affectionate young man who was able to assert his wants and desires in particular situations.

We feel that the main difficulty lay in our not being able to keep new staff and stand-in teachers properly briefed on the aims discussed with the original team. Staff in Ross's classroom had said on a number of occasions they felt that Ross was an inappropriate choice for Smart Wheelchair work because he was too physically able, and it was difficult or impossible to convince them of the educational goals for him which underpinned his choice. As a result, no innovative curriculum activity was ever set up for Ross, and the work became grounded on inappropriate mobility related activities. There was, in our view, little point in using the Smart Wheelchair to do poorly what he was capable of doing well using his rollator or crawling. On the other hand, activities could have been set up which were impossible using those mobility aids (such as combining his IntroTalker work with chair activities), but weren't.

Ross



Video recording began
Chair Introduction
Parent/staff Introduction
Chassis not working
Chassis replaced
In plaster therefore unable to use chair
Continuity of chair work
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Time spent on Task
no chair work chair used app. 7 times-->
no records kept
Staff in charge
Teacher 1
Key person
Teacher 2
Teacher 3
Nursery Nurse
Temp Teachers
Parents
seconded away
seconded away
no further information provided
New class
New class
Key person left
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school
(excl. holidays)
Malfunction



Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Switch
Bump Tools
Motion Tools
1
2
3
no diary information provided ->
KEY:
Forward using switched joystick
Joystick forward and right
Joystick forward, left and right
Joystick forward, left and right using QED hit switches
No bump/ safety bump and stop
Bump and turn
Bump and reverse
Timed
Momentary

****Replace before binding****

Progress Chart (blank side, should be even page number)

KEY TO MILESTONES

1. Ross goes solo.

2. P. comments on Ross's inquisitiveness about the chair and how proud of the chair he is.

3. He works on his own, at one point becoming tangled in the swing frame which he finds hilarious.
   "All responses are accidental. He is not linking hand movement to the direction he wants to go in."
   "He seems to get the idea that he has to move his hand right to move right and forward to move forward. Ross realises that he can do a task on his own."

4.4.3 Graeme

Introduction

Graeme was referred to the Smart Wheelchair project in November 1991. He was eight years old and the eldest child in a family of three who were very enthusiastic about the Smart Wheelchair project and what it might offer Graeme. He had just begun his second year in the Senior section of a special school run by a national charity. He has cerebral palsy with severe motor and learning disabilities. He required a spinal jacket to give him head control; rarely responded to visual stimuli; had very limited communication skills; and unknown cognition. He was often unwell and had frequent seizures.

Pre-project Profile

Personality and cognitive state

Graeme was described as a good natured, happy boy. He seemed to like rough and tumble play, music and football. When happy or excited, he would rock either in a standing frame or when lying on the floor, leading to speculation about self-stimulation. Generally, though, he was extremely passive and unresponsive. His understanding and cognitive abilities were difficult to assess because of his lack of responsiveness and communication difficulties.

Vision

His family noted that Graeme enjoyed watching football on the TV at home, and his mother also described him as being able to look at pictures in a story book, but there were queries about Graeme's vision. He did not seem to focus on objects or people although this may have been due to his general lack of interest and response. Some experiments in a darkened room with reflective paper and bright objects and a torch revealed that in general Graeme had consistent responses to these stimuli, with a delayed reaction or no blink to a light directed towards his eyes.

Hearing

The profile described Graeme as able to track and follow noises. He would also turn towards noise (as far as his spinal jacket would allow).

Expressive communication

Graeme seemed to enjoy interaction with familiar adults. Vocal communication was limited to crying to show distress. He smiled to show pleasure. He would raise his right hand for a "yes" response but this was inconsistent and often needed verbal prompting. "No" was no response. He appeared to self stimulate with his rocking movement either in his standing frame or in side lying.

Receptive communication

Graeme would move his head in the direction of a sound, but tended to have no great peer awareness and always required verbal prompts to communicate.

Education

Graeme was described as responding best to auditory stimuli with no obvious reactions to taste, smell or tactile stimuli. He had been using a hand raise switch and also a squeeze switch for computer or switch operated toy activities.

Mobility and physical skills

Graeme had limited head control. He could lift his head up when sitting for short periods, but required his head supported by a body brace. He had little voluntary movement, being restricted to control over his right hand and arm. He could raise his hand off a tray and could operate a finely set squeeze switch.

Initial video interpretation

The pre-intervention school videos show Graeme as a child who really responded to very little in his environment. One sequence shows Graeme in his standing frame during a class painting activity. His rocking movement causes his hands to move the paint around on the paper, but when the paint and paper are removed, he continues his movement. He mainly responded to sounds in the classroom although he shows little or no attention to any visual stimuli. He did not volunteer himself in a group situation and any responses had to be elicited from him with lots of encouragement.

The film at home also shows Graeme to be a passive child. Although he seemed to watch television the video shows that Graeme was not looking directly at it and he did not seem to be tracking anything on the screen. When a different stimulus was offered (an activity centre) and placed in front of him, he did not respond to the change. He did like movement games such as rocking on his father's knee: he lifted his head and his facial expression showed enjoyment.

School and home settings

Graeme had been placed in a class of more able children for one year with the hope that it would encourage greater responsiveness. A few months after the chair was introduced, both Graeme's key worker and his teacher moved. The new staff were enthusiastic and for a period of just over a year, Graeme was given lots of opportunity to use his chair. In addition, his parents wanted Graeme to take the chair home during all the holidays. Although their house was small and therefore chair activity was limited, Graeme nevertheless continued to use the chair at home. A ramped access to the front door and the back garden allowed Graeme to play outside with his neighbours and sisters and on one occasion the chair was also taken to his grandmother's house.

Aims and aspirations

General education aims
- to encourage simple rhymes and finger games
- to motivate Graeme and encourage him to be less passive

Communication and socialisation
- to encourage definite response
- to improve consistency of yes response
- to improve peer awareness
- to encourage face to face interaction
- to encourage exposure to a variety of adults in a variety of settings

Functional mobility
- none

Physical and life skills
- to prevent deformities
- to encourage head control and to facilitate voluntary movement
- to improve his voluntary control

The central aim for Graeme's use of the chair was for motivation. It was generally thought that he was becoming less motivated and less interactive, and less willing to tackle activities which were within his capabilities. The school team hoped that the chair would motivate Graeme and encourage responsiveness and participation. They also hoped that it would give an opportunity to assess his vision, perception and cognition in functional situations.

Chair, seating and controls design

The Bioengineering Centre at Princess Margaret Rose Hospital had previously built a seat insert for Graeme's manual wheelchair and they manufactured a frame to fit the insert to his Smart Chair. Graeme was already using a pneumatic squeeze switch (also designed by staff at the Bioengineering Centre) to control a computer and toys and this was transferred to the Smart Wheelchair also. Graeme began driving the Smart Wheelchair forward using the timed motion tool with either 'Bump and Stop' or no bump tools, depending on the activity and environment.

Using the Smart Wheelchair

Introduction

The chair was introduced in April 1992. Graeme's lack of response and passivity implied that it was vital to achieve successful, fun experiences over which he had control, in order to motivate him and build his confidence. The team therefore adopted a very tentative, child-led approach. He began by watching his helper drive the Smart Wheelchair but showed little or no interest. It was suggested that this might have been partly due to poor vision and so he was offered a seat on his helper's lap. The diary reports that his facial and eye expression changed immediately and he showed interest and enjoyment. He responded to the helper's commentary of what she was doing with the chair. His "yes" and "no" response was fairly consistent and there was slight evidence of some eye movement. After a few sessions he was riding solo and was responsive and smiling. He also needed little or no encouragement to operate his squeeze switch at this time. These small steps were regarded as major successes since for the first time he had shown evidence of intrinsic motivation to tackle an activity over which he had complete control.

Motivation

Over the next few months his control over the chair improved and he expanded his repertoire of activities to include games like hide and seek. During this session he was very responsive, alert and unusually vocal. When a team member suggested changing direction, he responded by raising his hand. During his period of hiding, he sat quite still, did not use his switch and smiled when the teacher was getting close to him. The staff commented that Graeme was usually in a good mood for the rest of the day following a Smart Chair session even if he had previously been irritable and unhappy.

Home use

In July 1992 the Smart Wheelchair was taken home during the summer holidays. His diary describes him as being slow to begin with soon gaining confidence. He was still using timed control and soon as the chair stopped he would squeeze his switch and move again. His parents describe him showing off to visitors and helping carry washing out to the garden for his mother. When asked later if he had been helping he became excited and vocal. His mother noted that after more sessions in the chair, Graeme was vocal and appeared to be making new mouth movements at times.

Steering

When he returned to school in August, he had a new key worker and a new class teacher. They continued work with him: on one occasion his key worker counted 205 switch operations during a single session driving around the school. Graeme seemed to be showing more head and eye movement and so the team decided to introduce steering. His key worker held a light action TASH leaf switch at the side of his head, encouraging him to turn his head and look where he wanted to go. This seemed successful and so two soft foam switches were permanently mounted on a bracket for independent use. These proved that Graeme had the motivation and understanding to use head switches, but they required excessive head movement an appeared to 'blinker' Graeme, so were replaced by two of the light-action TASH switches. The chair software was modified to give timed control for the forwards squeeze switch (for technical reasons the switch could not maintain an activation to give momentary control) and momentary control for the two head turn switches. A new brace also allowed him more freedom of head movement. His early attempts at direction finding were described as being "pretty random" and he seemed to enjoy going round in circles. When at home, his mother said he enjoyed trying to chase the girls.

Towards functional mobility

By March of 1993 Graeme needed no encouragement to drive by himself in the Smart Wheelchair. He seemed less inclined to turn obsessively in circles and more likely to use his forward switch to get himself somewhere. His key worker reported that she thought he was attempting to steer through doors and video taken shortly after this seemed to confirm that Graeme was attempting to steer himself - unsuccessfully - through the classroom door. Graeme continued steadily until the summer holidays, sometimes appearing lethargic but at other times quite active. His control was improving: sometimes he was successful at manoeuvring through tricky situations such as doors, but at other times he seemed to get stuck, going round in circles. His accuracy was also affected by problems of positioning his head switches in the correct place for him to operate.

Line Follower

In August 1993, the first Smart Wheelchair Line Follower was completed and the schools suggested that Graeme would be a suitable person to benefit from it. Although his head switches made him an unusual choice (because he had some control over steering), the staff felt that his control was not consistent or accurate enough and that he was frustrated and in danger of becoming demotivated. It was suggested that the Line Follower would provide him with more functional mobility around the school, while his head switches would still allow him to leave the line and drive independently. To reduce the potential for confusion while he was learning how the Line Follower worked, the team initially removed his head switches while he was following a line. The diary sheets suggest that he enjoyed the relative security and relaxation of being able to drive and let the chair follow the line up the school corridor, without having to constantly adjust his heading with the head switches.

Post-study Profile

Generally the post-intervention profile contained a great deal more information and observation than the pre-profile, indicating that the class team's aim of assessing his skills had been at least partially successful.

Personality and cognitive state

Graeme's parents report that he generally seems more interested in things and enjoys playing with his sisters in his Smart Wheelchair. The school staff noted that he enjoys chair sessions even if he started off the day grumpy. This contrasts with his pre-intervention profile when nothing could dispel his black mood. He particularly enjoys going outside, bumping over grass and different surfaces outside. His class team observe that although he appears passive, they can now see that he is not. He demonstrates recognition of familiar places from unfamiliar, looking around more in an unfamiliar environment. He remembers how to move the chair with head and hand and where particular objects are, such as the automatic outside door in the school. Some new persistence was noted when Graeme was in the Smart Wheelchair: the count of 205 switch operations during one session; and if the chair is not switched on he continues to squeeze until something happens. On occasion, he showed assertiveness by refusing to come out of the chair, continually squeezing his switch, or by deliberately creating a hold-up in the school corridor.

Vision

There is little difference between pre- and post-profiles regarding vision, although more observations have been collected post-intervention showing that the class team had greater opportunities for assessment. He appears to use his vision to explore his environment, looking around and choosing which way to go when in his Smart Wheelchair at home and in school. He occasionally made eye contact with people speaking to him.

Hearing

The class team felt that Graeme responded more to noise.

Expressive communication

Graeme "yes" response by raising his hand is still inconsistent. Now he also uses a bright expression or smile for "yes" as well. "No" is still a nil response. His parents report that he vocalises a lot especially when excited. This is not observed in school apart from in music therapy. The class team think he makes definite choices of direction when in his Smart Wheelchair, but this has not generalised and he only chooses inconsistently between two objects. Although the class team feel that he makes choices about the direction he wants to move, they also feel that he is not consistent when actually making the choice with his head switches. However, his key worker and the Formative Evaluator think that he is choosing appropriately. His physical control difficulties make this aspect of cause and effect difficult to determine.

Receptive communication

Graeme's comprehension is still difficult to assess since he has no consistent eye pointing between two choices. He seems to recognise his name in class and shows pleasure when listening to stories. His parents feel that his understanding is good.

Education

Graeme uses his three separate switches in the Smart Wheelchair although his understanding of the effect of the turn switches is open to question. He attempts to use his chair to solve mobility problems such as manoeuvring through doorways.

Physical/mobility skills

Although Graeme's unsupported head control is still noted to be poor by the class team, his parents feel that it is better both with and without his spinal jacket. Graeme does not now participate in rolling in the classroom, where previously he did. The class team feel that he understands the purpose and power of mobility and how he can use the switches and chair to achieve it, but his control is not good enough to give fully independent functional mobility. His parents report that the chair has provided some degree of independence which he has never previously experienced and that he is never bored when using it.

Long term process measures

Graeme's Continuity Chart shows that he had regular opportunities to practice both in school and at home. His usage appears to reduce slightly towards the end of the intervention and this may have been because he was beginning to exhaust the limits of his control and get less enjoyment out of his chair use.

The Tool Chart shows steady progress in his acquisition of control and mobility skills, while the even spread of Milestones through the intervention suggests that new challenges were offered and mastered at reasonable and regular intervals. It is unfortunate that data was not collected beyond the end of the formal recording period in July 1993, because Graeme's chart and diary suggests that he was becoming less interested in the chair, possibly because he had explored all that it could offer him with his controls and the basic Smart tools. To maintain progress and interest, it is likely that more functional independent mobility was required. His physical limitations mean that this could only be provided by improved chair-based tools, or by use of a switch-operated scanner for turning as well as forward motion. Although the line follower appeared to provide an element of functional mobility, his control off-line was still limited and the team hypothesise that he might benefit from alternative bump tools such as 'Bump and Avoid', or Rangefinder-based ''SlowDown'', 'Remote Bump' or 'Avoid' tools to help him navigate around cluttered environments more effectively. Unfortunately, it was not possible to provide these prior to the end of the project.

Graeme is similar to many severely disabled children with very limited control, who have a 'learned helplessness' contributing to passivity and a lack of response. His progress has been good considering his lack of interest in any previous self-controlled activities and illustrate the power and fun that powered mobility can offer even although he has not achieved accurate fine control over his chair.

SequenceView **Analysis**

The over-riding aims of the intervention for Graeme were to prevent further de-motivation and passivity and so the *SequenceView* transcription and analysis aims to record and identify evidence of whether this happened. Again, initiation (through vocalisation, switch use, eye contact or body language) and response were chosen as indicative measures of motivation and activity.

Pre-intervention video analysis

The pre-study plot is taken from a transcription of a video sequence when Graeme was in his classroom taking part in a class painting activity. He is supported in his standing frame against a table with paper and paint. Initially, there is music playing in the background (this is the 'Machine' given in the plot). He is rocking back and forth and moving the paint around, but it is very difficult to decide whether Graeme is engaged in the painting task or whether his rocking is simply self-stimulation. During the 19 minute sequence, he only initiates interaction 7 times to which no response is recorded at all. In contrast, his teacher initiates on 146 occasions to which he responds 44 times.

Post-intervention video analysis

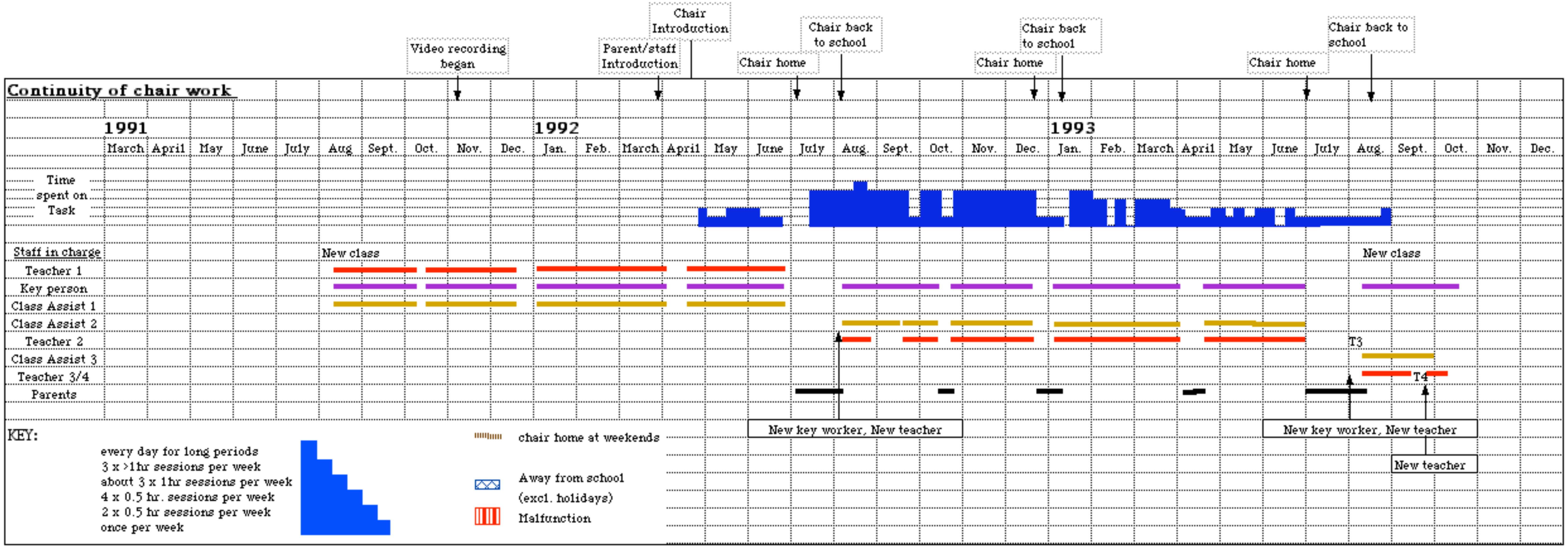
The post-intervention sequence lasts nine minutes and represents a session when Graeme was in the early stages of trying out his TASH 'lollipop' head switches for steering. He is in his classroom, trying to manoeuvre around furniture, objects and equipment and appears to be attempting to steer out the door.

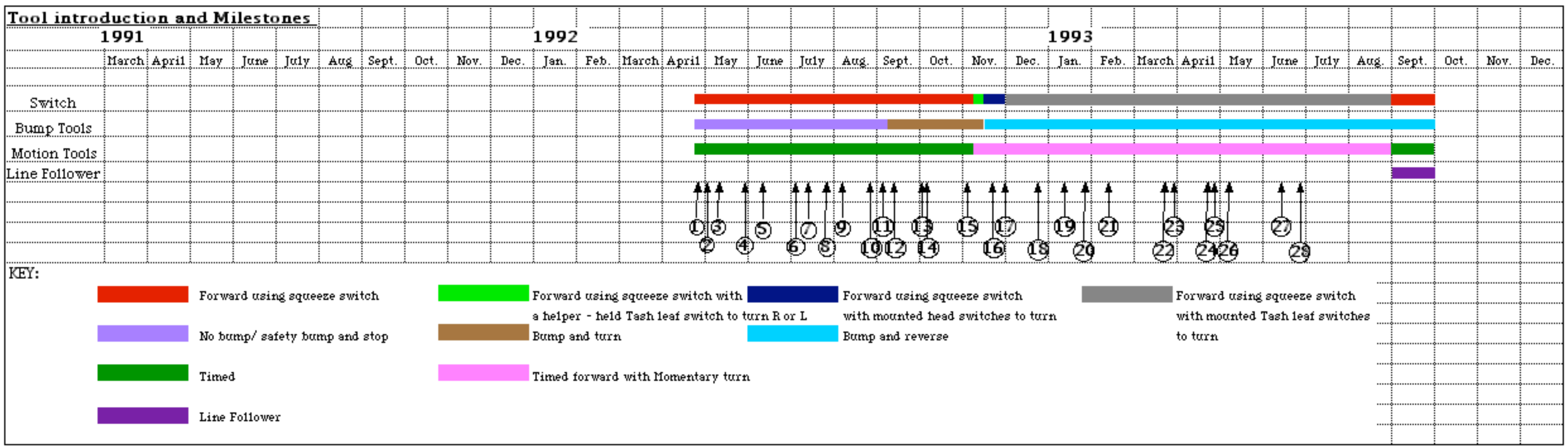
He uses his three switches to initiate 38 times, spread evenly over the nine minutes and gets 60 responses from his teacher or from the Smart Chair. His human partner initiates 58 times, to which Graeme responds 25 times. His Smart Wheelchair initiates 7 times, reporting collisions.

Graeme's increased activity when driving his chair is shown by his increased initiation count: 38 over 9 minutes post, compared with 7 over 19 minutes pre-intervention. He is also far more successful in obtaining a response to these initiations: 60 post compared to zero pre-study. The balance of initiations between Graeme and his human partner (38/58 compared with 7/146) shows that he has more control over the interaction.

The figures support the observations from staff and parents, that Graeme is more assertive and active when using the Smart Wheelchair.

Graeme


Continuity of chair work
Video recording began
Parent/staff Introduction
Chair Introduction
Chair home
Chair back to school
Chair home
Chair back to school
Chair home
Chair back to school
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec.
Time spent on Task
Staff in charge
New class
New class
Teacher 1
Key person
Class Assist 1
Class Assist 2
Teacher 2
T3
Class Assist 3
Teacher 3/4
T4
Parents
New key worker, New teacher
New key worker, New teacher
New teacher
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school (excl. holidays)
Malfunction


Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec.
Switch
Bump Tools
Motion Tools
Line Follower
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
KEY:
Forward using squeeze switch
Forward using squeeze switch with a helper - held Tash leaf switch to turn R or L
Forward using squeeze switch with mounted head switches to turn
Forward using squeeze switch with mounted Tash leaf switches to turn
No bump/ safety bump and stop
Bump and turn
Bump and reverse
Timed
Timed forward with Momentary turn
Line Follower

****Replace before binding****

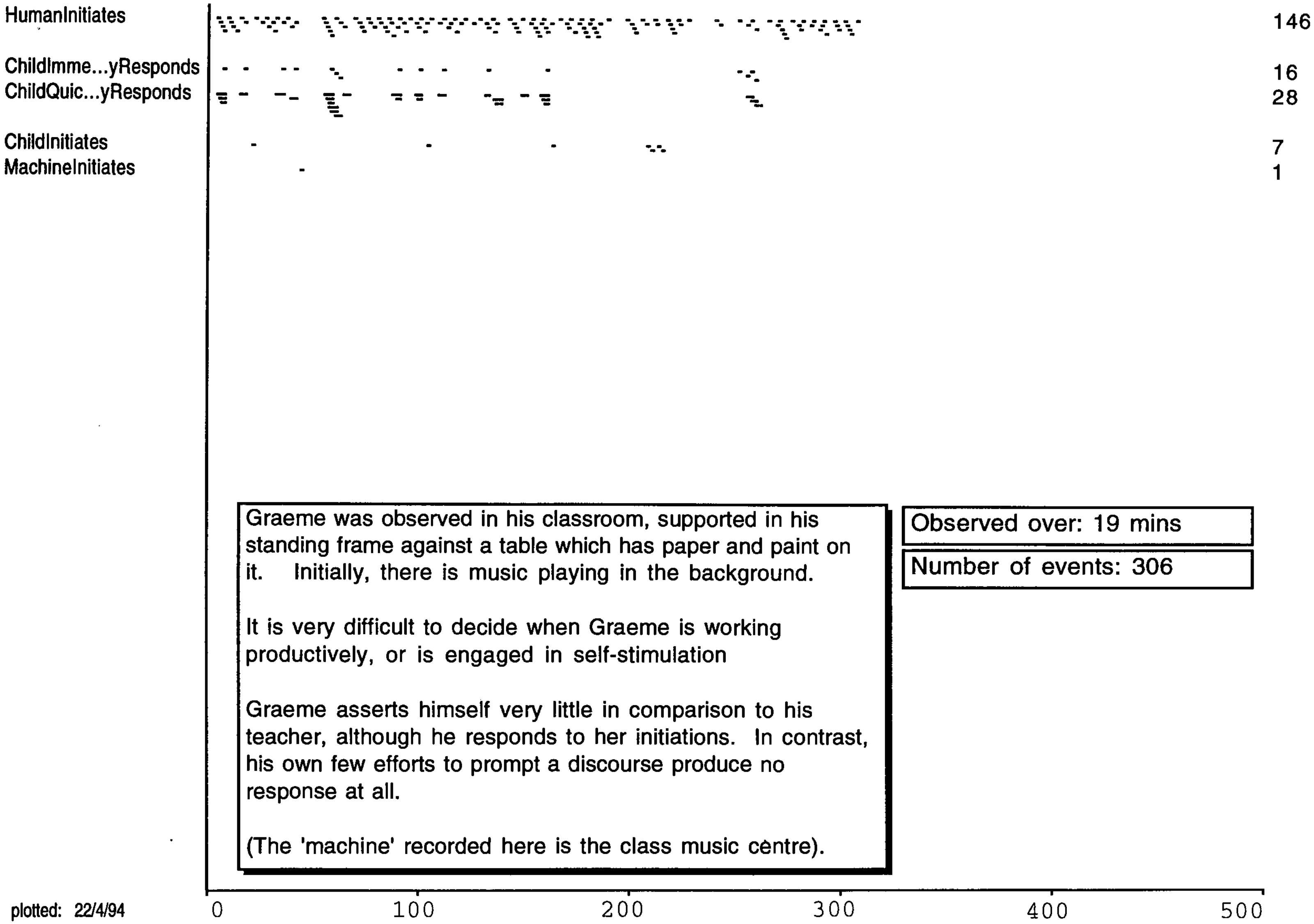
Progress Chart (blank side, should be even page number)

KEY TO MILESTONES

1. Graeme is initially unresponsive, but as soon as he is taken on to C.'s knee, he becomes more animated and participative.
2. Graeme is operating the switch from C.'s knee.
3. Graeme goes solo.
4. Graeme is outside: he is not switching much, but sits moving his head. He is noted as [enjoying] feeling the breeze on his face.
5. Graeme plays hide and seek, vocalising where appropriate and is participative. The Music Therapist has a good session immediately following the chair session.
6. "Graeme is slow to begin with, but in the hall, after being out in the garden, he gives huge smiles and his eyes sparkle. He moves along, hardly giving the chair a chance
   to stop and does not wait to be turned. He drives into the bedroom and up to the TV in the living room."
7. “He shows off to visitors. Outside, he moves the chair well when neighbours come out see what he is doing. When neighbour's daughter comes out, he moves over to her right away.”
8. He helps Mum hang out her washing. "When asked by others if he is being helpful, he becomes excited and vocal. After most sessions in the chair, Graeme has been very vocal and appears to be making different mouth movements at times.”
9. S. reports 205 switch operations when out and about around the school.
10. His gutter arm support is being repaired: "he copes remarkably well using switch without it. He is very interested in photos in the corridor". Chair is used a lot in class - Graeme is tired and fretful, and happier after chair is switched off.
11. "Graeme takes off immediately he is put on the chair! The staff are pleasantly surprised that he needs no coaxing."
12. "He spends 3 hourly sessions making no progress at all. His hand does not even flicker on the switch (he has been very twitchy all week and has a red ear)."
13. The new brace “means that he can move his head to each side but is still be able to look directly ahead at where he is going”.
    “Good session with Graeme smiling and happy, and really looking around him."
14. "Graeme goes down the corridor into the front hall and proceeds to open the ‘magic’ door. He completes a circuit into the back hall 3 times and thoroughly enjoys being able to open the door by himself. He smiles a lot and really seems to be taking in his surroundings."
    "He looks around, smiling and taking note of lots of people passing by. He enjoys the traffic passing and cars coming into and leaving school."
15. "He is really looking around and seems keen to stop and listen to conversations."
    "He is becoming quite successful at restraining himself for a lot of the time if I ask him not to squeeze the switch as we need to keep the chair on stop."
16. "We are concentrating on getting Graeme to indicate direction to a head controlled switch for his own operation. He is looking quite well in the direction he wishes to go."
17. "Graeme has a great time going round in circles up and down the corridor. He stops and faces P. when she speaks to him.”
18. "He enjoys being able to chase the girls."
19. His attempts at direction finding are pretty random. He seems to like going round in circles.
20. Graeme manoeuvres himself through the classroom door on at least two occasions.
21. Graeme is trying to see over his shoulder to find out if K. is following him.
22. "He needs no instigation to take himself off in the Smart chair, and has been a lot less inclined to turn obsessively in circles. He has been much more willing to use his forward switch. He manoeuvres the chair and still enjoys keeping people waiting in the corridor, making them dodge around him. He looks around at everyone and everything which takes his interest."
23. "He is in a very stroppy mood before going into the chair, but immediately stops crying and takes off again, primarily to follow R. He decides that he wants to go out to the street instead and does not deviate but keeps straight on until we reach the front courtyard when he does a fair bit of turning and exploring without much stopping."
    "Graeme makes full use of his time and is reluctant to return to the class for lunch, looking around him and yet again using his forward switch a lot more instead of turning all the time."

24. "Graeme performs quite well though is a bit slow in responding. He isn't really interested in the traffic lights F. has set up in the corridor and hall for R. so we just go through the 'magic door' a few times instead."
25. "For a change, he starts off heading up the corridor instead of to his right. He finds it a bit uninteresting and comes back down again. He wants to go outside, but it is very cold and wet so we have to persuade him otherwise."
26. "He has been very quiet and rather lethargic so we're not getting a lot out of using the Smart chair."
27. "As soon as I switch on the chair this morning, Graeme is off at a fair lick, hardly giving the chair time to stop before squeezing the switch again. He uses the head switches intermittently along with the forward switch and is not locked into turning for a long time in a circle."
28. "Graeme is brilliant in the chair today. He seems quite decisive about where he wants to go, choosing turn appropriately and then forward to go down the corridor. He definitely **decides** to operate the 'magic' door and is heading towards outside, but is moved on by S. to Music Therapy."

Graeme (Pre-study) 14/11/91



Graeme was observed in his classroom, supported in his standing frame against a table which has paper and paint on it. Initially, there is music playing in the background.

It is very difficult to decide when Graeme is working productively, or is engaged in self-stimulation

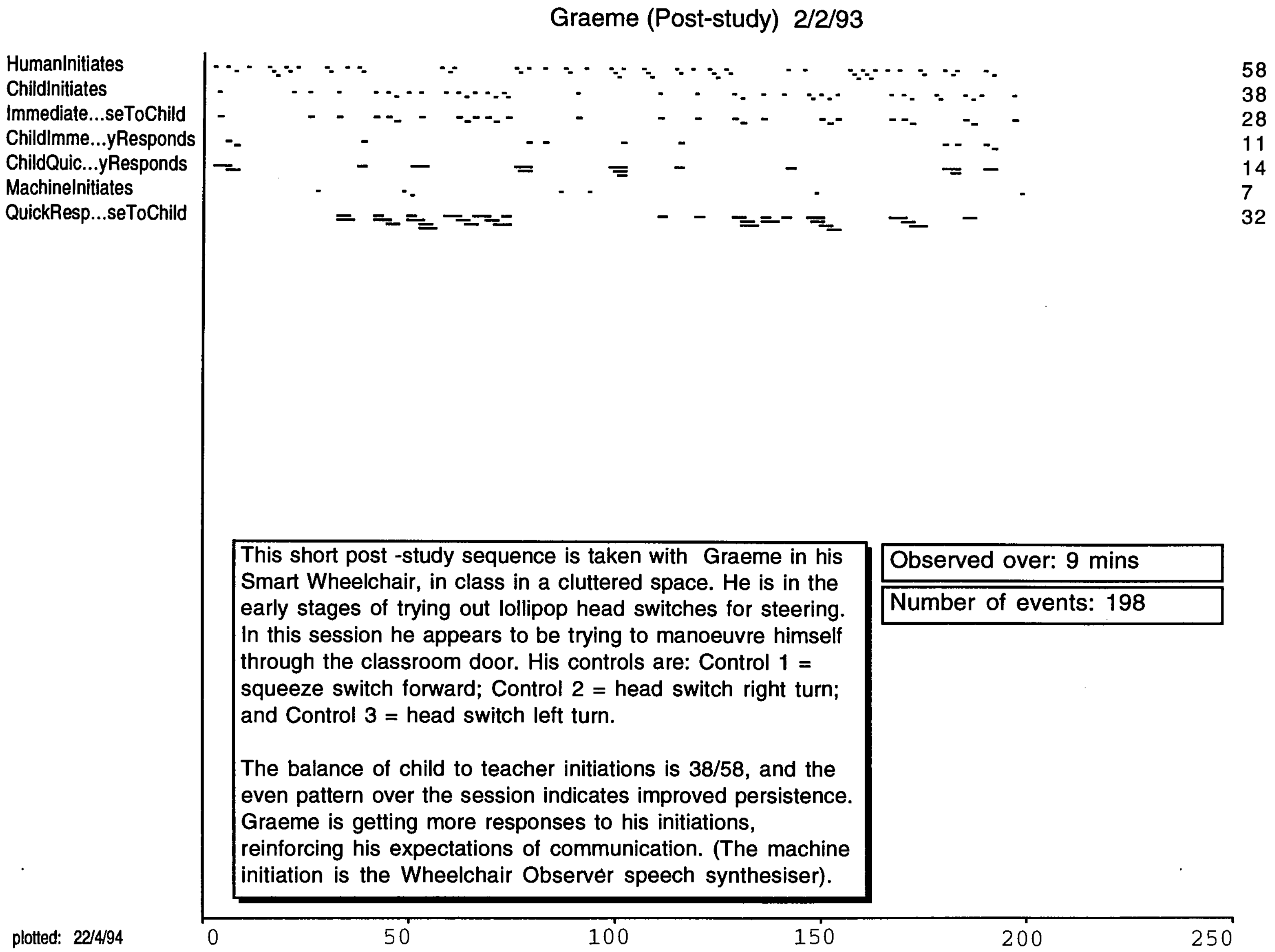
Graeme asserts himself very little in comparison to his teacher, although he responds to her initiations. In contrast, his own few efforts to prompt a discourse produce no response at all.

(The 'machine' recorded here is the class music centre).

Observed over: 19 mins

Number of events: 306

plotted: 22/4/94



This short post -study sequence is taken with Graeme in his Smart Wheelchair, in class in a cluttered space. He is in the early stages of trying out lollipop head switches for steering. In this session he appears to be trying to manoeuvre himself through the classroom door. His controls are: Control 1 = squeeze switch forward; Control 2 = head switch right turn; and Control 3 = head switch left turn.

The balance of child to teacher initiations is 38/58, and the even pattern over the session indicates improved persistence. Graeme is getting more responses to his initiations, reinforcing his expectations of communication. (The machine initiation is the Wheelchair Observer speech synthesiser).

Observed over: 9 mins

Number of events: 198

plotted: 22/4/94

4.4.4 Cameron

Introduction

Cameron was a cerebral palsied child with severe motor problems which affected all four limbs. He was 3.5 years old when the project started, and had been attending an Early Education Centre, moving to the nursery class of the primary school soon afterward.

Described by those who knew him as bright, Cameron appeared to be hearing and seeing well, and was developing a mix of communication skills based around eye pointing and rather poor speech.

His parents were supportive of the project, but anxious to ensure that Cameron's involvement in it didn't prejudice efforts made to foster other developmental efforts, in particular walking practice and associated physical skills.

Pre-project profiles

Cameron is still discovering his abilities and limitations. He is also therefore coming to realise that some of these limitations cannot be overcome in the way in which he sees his peers and family overcoming them, and is at the developmental point when anger and frustration, or passivity, or both set in.

Personality, cognitive abilities and sociability

Cameron was described as a biddable, well-motivated, usually happy boy with a good memory. He was sociable both with adults and other children, and inquisitive about what was happening around him. Cameron knew the names of his classmates and family members and showed colour preferences. He was particularly interested in watching people's feet when they walked, which his mother took to be related to his awareness of his own lack of mobility.

Cameron was not afraid of new activities, and liked to control the situation as much as possible.

Vision

There was no evidence of any visual defect.

Hearing

Cameron appeared to have no hearing defect. He was able to recognise familiar voices and able to fit words to songs that he knew.

Expressive communication

Cameron frequently initiated conversations, shouting "Hi" in order to gain attention: he was good at making and maintaining eye contact with people he was communicating with. He had consistent 'yes' and 'no' responses and used eye pointing as a back-up to vocalising. Despite enjoying being with other children in a classroom situation, he didn't initiate interaction with them, generally interacting with other children through an adult. Cameron's speech was poor, but he was beginning to use it more and more as a means of communication.

Receptive communication

Cameron was described as having good understanding in conversations about common concrete objects, animals, body parts and simple abstract concepts. No formal comprehension tests had been carried out at that stage. He was also responsive to changes in tone of voice and anticipated words and songs.

Education

Despite working on basic number concepts through everyday activities, there was no evidence that Cameron understood them. He understood the concepts of right and left though on some occasions got confused. Cameron's colour matching skills were described as inconsistent (although he consistently indicated that his favourite colour was blue).

Physical skills and mobility

Cameron has quite a strong ATNR, particularly affecting his right arm, and had a number of problems with grasp and release in both hands. Despite his physical limitation, he tried hard, and on some occasions was able to copy actions that he saw. He was described by his mother as becoming frustrated at his lack of mobility, desperately wanting his mother to let go of his hands when he was dancing.

Initial video interpretation

The pre-intervention school videos show Cameron as a bright child who was eager to participate in group activities in the classroom setting and confirmed that, despite enjoying peer company, interaction was mainly limited to adults. He showed a great determination to be first in a choosing activity and seemed quite motivated to try activities that for him were quite challenging.

Equally the videos taken at home show a child who was eager to communicate but very often showed frustration when his partner was unable to understand what he wanted to say. He also demonstrated the manipulative behaviour that was described by his mother and his demand for one-to-one adult attention.

School and home settings

Cameron attends the nursery department of a grant-aided school supported by the Scottish Council for Spastics. The nursery department is well known for its interest in the use of group work styled on conductive education. It is a busy environment, with a lot of materials and furniture for the space available, and run on quite a formal timetable structure.

At home, Cameron and his family lived in an upper flat, with all that implied for access. Early in the project, Cameron's parents had a second child.

Aims and aspirations

The team identified the following curriculum aims at the outset of the project. They noted that Smart Wheelchair activities were more relevant in some areas than others, but wanted to ensure that they were set against the broader record of aims, and did not distort it.

General Educational aims

- to develop appropriate mobility related abstract concepts; for example, behind, beside, near
- to increase his understanding of concrete environment through clay and tactile activities
- to develop understanding and enjoyment of symbolic representation and play
- to develop computer based play
- to increase awareness of different body parts

Communication and socialisation

- to encourage positive interactions with children and adults and use vocalisations meaningfully
- to build on word approximations, impute with meaning, and give adult model
- to continue to work on two word utterance level
- to encourage the use of someone's name when speaking to them
- to encourage speech sounds imitation, and to provide opportunities during play for this
- to encourage the use of eye pointing and looking skills to support his spoken message
- to improve comprehension
- to extend concept and vocabulary range
- to encourage interaction with peers
- to encourage cooperation at all times

Functional mobility

- to encourage active non dystonic trunk extension and improve walking pattern
- to improve weight bearing through upper limbs
- to encourage active functional movement, for example, rolling and creeping

Physical skills

- improve eye/hand coordination
- to maintain range of movement
- to improve balance and saving reactions, therefore improving sitting balance and encouraging dependent sitting
- to normalise dystonic patterns of movement
- to encourage a better pattern of grasping and releasing and to discourage the use of reflexes to achieve finger extension and an open hand.

Functional aims for the Smart Wheelchair

Cameron's mother had an agenda of practical, functional mobility aims centred around home life: for example, that Cameron should be able to go to the fridge and choose what he would like for dinner, or to have the independence to be able to leave the room and go where he wanted, when he chose. She saw the Smart Wheelchair as providing a means of opportunity for this to happen.

Assessment and adaptation - chair, seating and controls design

As Cameron had no manual wheelchair seating, a system was designed and built for him from scratch. Because he was quite small, the Bioengineers at Princess Margaret Rose Hospital felt that a modified Britax car seat would be the most suitable option.

Cameron was not using switches during his day to day school activities, so no clues existed about the most suitable control device for him. Since he had difficulty in targeting due to his ATNR, it was suggested that a joystick gated to allow forward direction only might be the most suitable starting point. His ATNR was much more marked on his right side, and Cameron demonstrated no hand dominance, so it was decided that the joystick would be set up for his left hand, slightly off line to the left side, and mounted on a modified tray. Because of Cameron's poor grasp and release and because his other class programme of work included requiring Cameron to hold on to a vertically placed rod, the staff suggested that the joystick should also be rod shaped.

It was thought that Cameron would start his chair programme using the 'Timed' tool, with the wheelchair providing 'Bump and Stop' services for collisions.

Smart Wheelchair work

Cameron was introduced to the Smart Wheelchair in May of 1992, his class teacher being his key worker for Smart Wheelchair work at the outset. He surprised everybody involved by his nervousness at using the chair, needing several sessions riding with the helper before having the confidence to ride solo. He continued having frequent sessions in the Smart Wheelchair until the summer holidays.

At that point, because his teacher moved classroom, Cameron was appointed a new key worker who was then trained in the use of the wheelchair. For a period, the classroom also had a temporary teacher and so timetabled sessions were difficult to organise and infrequent (see the Process chart). By the beginning of October the CALL team were becoming concerned about Cameron's access to the Smart Wheelchair, and the issue was raised at the Smart Wheelchair meeting. However, his replacement teacher did not arrive until the beginning of December, when a class team meeting was arranged in order to address the problem.

Meanwhile, after the October break, the team continued to encourage Cameron's use of the chair by widening his range of controls. However primitive, steering of some form is needed early if children are not to have the motivation due to their early, single directional movements turn to frustration by the limitations the tool imposes. Joystick steering was (and is) difficult for him, and he could not separate his control movements. To help him to turn (initially left), we set up a second, switched control. However, he had great difficulty releasing the joystick to operate it. After using the switch, he also had difficulty getting his hand back on to the joystick. It was reported in his diary that he kept pointing to where he wanted to go, but did not really understand how to use the switch to turn himself round so as to get there. The team did not want to increase his frustration, and wanted the limited amount of time in the chair to be positive. Cameron once more returned to having control over forward direction only.

Because it was clear that Cameron understood what the joystick forward control did, he was introduced to the momentary tool in order to try and improve his hand control skills and he was offered the opportunity to explore by being given ‘Bump and Turn’. He showed some success with this combination.

Perhaps because of the long gaps between sessions, by the time he returned to using the chair in early 1993, although Cameron could still initiate chair moves well, he had lost the ability to stop appropriately. A lot of the team’s effort in the early part of 1993 was put into playing games involving stopping. At the beginning of February, we believed that he was once again ready to try steering, and several combinations of control designs and physical limb restraint and support were tried to offer Cameron a change of direction. Cameron persisted from February to May with his left arm gaitered and the joystick gated forward and right. His diary notes that his arm tended to gravitate towards the midline, whereafter he found it quite difficult to push forward once more: as a result, he was apt to go in circles.

Again there were large periods when Cameron did not have access to the chair and we tended to find that from session to session he had to go through a relearning process at the beginning of the session so that in total it did not seem that he made much progress over that period of time.

However, despite this, he still seemed very motivated by the chair although very distractible. The circumstances were not ideal. Chair use was confined to withdrawal from the classroom situation and activities mainly took place in the hall area which was the common thoroughfare to any of the other classrooms in the Junior School.

Because of the problems of access to the flat, and the organisation and effort surrounding the new baby, Cameron’s parents did not take the Smart Wheelchair home until late in the project. They had always been willing to do so, but the practical problems took time to overcome.

By June, the CALL team were concentrating on improving feedback. The aim was to try to help his proprioceptive awareness by incorporating an audible and physical click to the joystick. Cameron tried a large QED joystick but because it had quite a large shaft length, this needed a lot of physical control of his upper arm to be able to maintain the operating position and proved too difficult for him. In the period of time before the summer holidays, he was given a small switched joystick, again with an audible and a tactual click although by now the project was running out of time, and this was never tested properly.

By the end of the summer 1993, Cameron had progressed little beyond the gains made during the early months, having understanding about and control over forward direction, but really being unable to control the turn. He nevertheless remained motivated and enjoyed Smart Wheelchair time, but still has very little opportunity to learn and improve on his physical skills due to lack of access time to the chair.

Post project profile

In recording the changes in his profile, we make no claims for the influence of augmentative mobility: Cameron has had very little opportunity to use the Smart Wheelchair beyond the early intensive sessions.

The classroom team who contributed to the post study profile had changed: the key worker was different, and the temporary teacher was not then available. This team’s perception of Cameron had altered, with more variable judgments being made of his overall abilities. Some members of the school team were now questioning Cameron’s memory; saying that unless a task was overlearned and became a real routine, he forgot the skill quite quickly. (In a different context, though, he is reported as being able to learn play routines quickly.) His colour matching skills were poor. What was described as being inquisitiveness in the initial profile was now being highlighted as a problem of poor attention skills and distractibility in the classroom. They also felt that his eye pointing and fixing was unreliable, again because of the attention factor. The school team had been trying a scanning system with him but felt he didn’t have a good understanding of it and frequently missed items on a E-Tran frame: again they felt it was probably due to lack of attention and concentration.

It was also noted that despite the fact that Cameron still enjoys activities and is participative, he likes to have a more passive role within that situation. He likes to be entertained and doesn't really like to have to do the work himself. Some team members were now describing Cameron as not being a greatly motivated young man; being easily put off; being aware of his failures and limitations. They pointed up a lack of persistence, recording that once he had tried a new task a few times and was aware that it was difficult, he often would stop and ask for help or refuse to do it.

The classroom staff still felt that mobility was a good motivator for Cameron and recognised that because of his access problems, he could have done with quite a bit more practice. Cameron's interest in his peers had seemed to change, being now at the stage where he would initiate conversations with another child and interact with children who would give him a response.

Other significant changes are noted below.

Expressive communication

Cameron's speech had improved over the year. Although sometimes still hard to understand, his vocabulary had increased and his language was still developing. He is now flowing two to three words together, is aware of turn taking and will await his turn. He will persist in communication efforts.

Receptive communication

Cameron's understanding is improving in one to one conversation, but this was felt to be variable in the classroom situation when he's open to many distractions. He is good at understanding objects, symbols and pictures, and can learn the rules of a new play routine quite quickly.

Education

Cameron is still at a pre-number level and number work has not been a high priority. The team felt that Cameron had only weak concept of colour. They thought that he might be able to colour match but he really had not succeeded in labelling objects with a colour. He was not at a stage that the class team were providing him with a word recognition task.

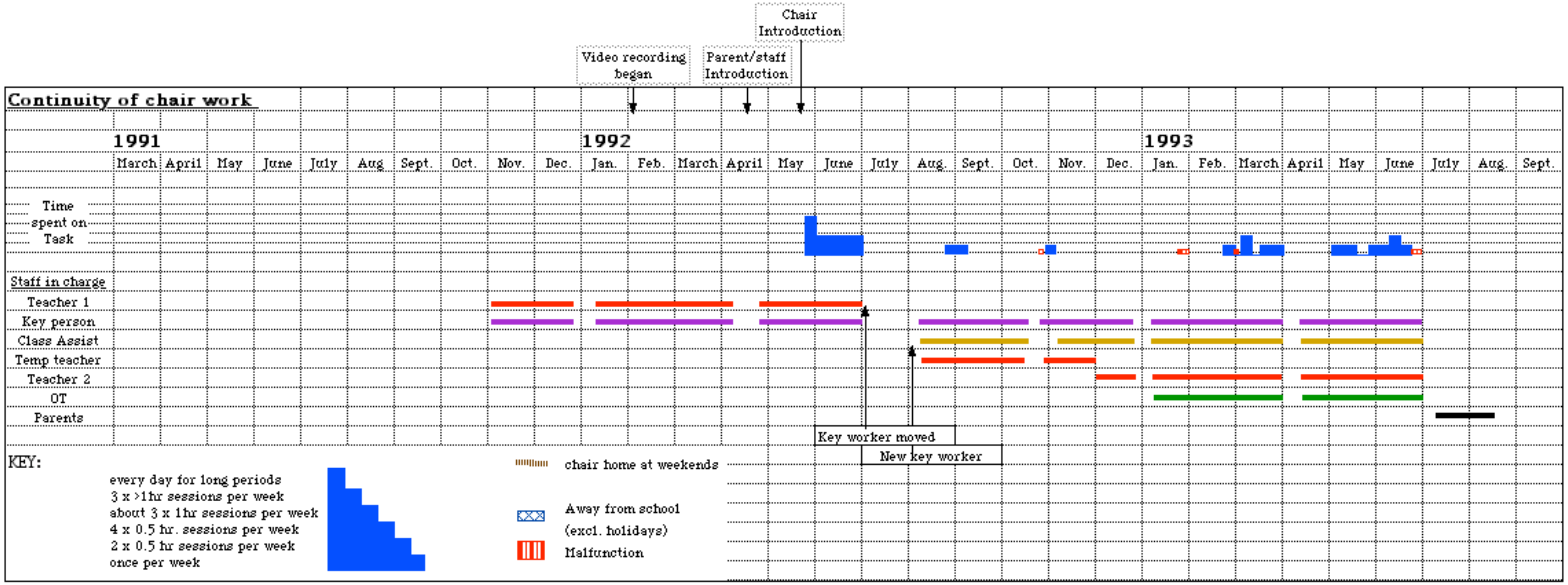
Physical mobility skills

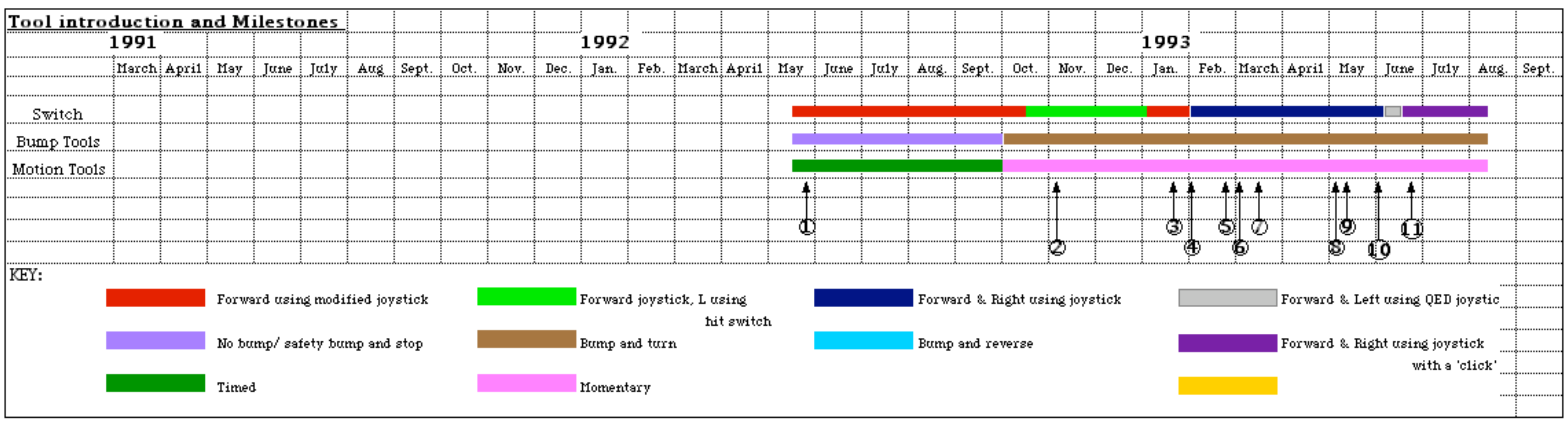
The class team felt that Cameron's head control was better. He was able to maintain it more in the midline and this was even better when he was sitting upright. They also felt that he had a better control over his ATNR. He can now sit holding on to a grip wire unaided, and can sit cross legged for about 20 seconds. He is rolling with assistance. Cameron also has limited independent mobility in the Smart Wheelchair and understands the power that the Smart Wheelchair can offer him. Cameron still has a lot of difficulties with his hand control much of which is due to his ATNR.

Many of the issues which are emerging as causes for concern are exactly those which the wheelchair is intended to address, and it is particularly disappointing not to have made better use of it. Cameron remains a sociable child with a good sense of humour. His mother continues to have a strong belief that augmentative mobility will be important in Cameron's future, and is keen that his Smart Wheelchair work continues. The problem for the project team highlighted by Cameron's case study is how to promote the integration of such systems into an already highly structured curriculum in such a way that they survive staff and class changes.

Intentionally blank

Cameron


Chair Introduction
Video recording began
Parent/staff Introduction
Continuity of chair work
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Time spent on Task
Staff in charge
Teacher 1
Key person
Class Assist
Temp teacher
Teacher 2
OT
Parents
Key worker moved
New key worker
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school
(excl. holidays)
Malfunction


Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Switch
Bump Tools
Motion Tools
1
2
3
4
5
6
7
8
9
10
11
KEY:
Forward using modified joystick
Forward joystick, L using hit switch
Forward & Right using joystick
Forward & Left using QED joystic
No bump/ safety bump and stop
Bump and turn
Bump and reverse
Forward & Right using joystick with a 'click'
Timed
Momentary

****Replace before binding****

Progress Chart (blank side, should be even page number)

KEY TO MILESTONES

1. Cameron goes solo.
2. He has difficulty releasing the joystick and getting back on to it when using the switch. He keeps pointing to where he wants to go, but does not really understand the process of hitting the switch to move himself round.
3. He plays a game of 'stop', managing to bring his hand back to the neutral position instead of taking it off the joystick altogether. Asks F. to come and turn him around.
4. He shouts 'Help me' when trying (and not succeeding) to go forwards. By end of first session, it looks hopeful that he will cope with forward and right while wearing an arm gaiter.
5. “He is apt to go in circles, with his arm gravitating to midline and, although he is able to push forward, it’s more difficult. He can’t get out of difficult corners, but calls for help twice. If his hand comes off the joystick, it is also quite difficult for him to re-access the position. He is asked to come towards us in a straight line and to look forward."
6. "His use of the switch improves as the session continues, and he makes it back to the speech therapy room with fewer detours, but again has difficulty maintaining the forward movement and in stopping promptly when necessary."

   "He is asked to go into the speech room, but he chooses to go to the toilet! He still tends to go round in circles."
7. "He is much better going forward and stopping on request, and manages to guide himself into his classroom and stop before crashing."

   “There is a lot of disturbance from people going past and he can’t concentrate at all. Every time he tries, people call his name and he has difficulty stopping when going round and round. He tends to release his whole hand for stopping and then finds it hard to place his hand back again.”
8. "Cameron is still easily distracted. It seems to help if he goes through the moves of forward, sideways and stop before starting the session. The bubble pack is very motivating, and Cameron laughs a lot. Cameron needs to be reminded to ask for the door to be opened before going into the classroom."
9. "He has difficulty stopping at the right time and requires lots of verbal encouragement to manoeuvre chair appropriately. He interacts well with the teacher. He then moves to physiotherapy and again asks what they are doing. Cameron has great difficulty turning the chair. We move outside and play ‘chases’. He enjoys moving about outside, but has difficulty turning the chair."
10. "Cameron’s visual attention is poor. He tends to round down over the switch and then has difficulty pulling it back to stop. We play ‘Ring and Ring of Roses’, turning the chair round by moving the switch to the right. He manages this better, but has difficulty stopping to watch me fall down."
11. "Click 2 way joystick is in place, but he still has problems stopping. The noise is good at reinforcing 2 way position."

4.5 Group 4: Combining Mobility and Communication Aids

4.5.1 Alan

Introduction

Alan was 15.5 years old when referred to the Smart Wheelchair project in April of 1991. He was described as an alert young man interested in his surroundings and other people. He was an only child in a family who were keen for him to have as many opportunities to extend his learning as possible. Alan had only experienced technology in the last couple of years and his mother had a BBC computer and switches at home. This interest extended to the Smart Wheelchair and his family were excited at the opportunities the chair could offer him. Alan was described as a severe spastic quadriplegic with postural deformities. He attends a Lothian Region school for children with multiple, severe learning difficulties.

Pre-project Profile

Personality and cognitive state

Alan's pre-project profile described him as having variable attention and a tendency to be moody. He appeared to have a good memory of people, objects and situations and was very sociable and responsive to a wide range of stimuli. He liked to be told what was about to happen to him and became unhappy in a situation about which he had not been forewarned. He demonstrated problem solving abilities when the method of switch operation on a computer activity was changed and he explored and adapted to it. He enjoyed being handled and touched but also demonstrated a desire for privacy when being changed. With individuals, he had definite likes and dislikes. He showed that he could recognise some pop music.

Vision

It was thought that Alan had no visual problems although no objective assessments had been administered. His profile reports his visual field extending well to the right and the left; he could eye-track; and he would fix and follow objects. Colour discrimination had not been tested.

Hearing

Alan had no discernible functional hearing impairment. When tested he could locate quiet and loud sounds of varying pitch.

Expressive communication

Alan was able to express pleasure, upset and annoyance using body language, vocalising with his left index finger. His teacher reports him eye pointing to indicate choice of a particular object. Interpretation of his eye pointing was problematic and often it appeared that communication partners misunderstood him and he would refuse the choice which his partner had concluded. Alan did not have a yes or no response. He would turn take appropriately, vocalising lines of songs when it was his turn. His teacher was introducing a switch-operated rotary pointer board communication system with variable results. Alan would use his index finger as a flexible means of communication to initiate communication and indicate emotions such as anger, happiness or depression.

Receptive communication

Alan used visual cues and expressions from classroom staff. He could follow and track the course of communication in general group conversation and would shout to join in. His mother reported that he appeared to notice and respond when people spoke about him in a derogatory manner.

Education and cognition

Alan had an understanding of cause and effect and was able to operate keyboard, lights, tape recorder, using a mercury tilt switch and a hit switch. He was able to use both at the same time.

Physical and mobility skills

Alan had a bad spinal scoliosis. He could maintain his head in the upright position in the midline and turn it to left and right, with a dominance to the left. Both lower limbs were windswept to the left; both hips were dislocated with fixed deformities and no purposeful active movement. He had increased tone in his right upper limb, a dislocated elbow and fixed deformities at both elbow and the wrist and the hand. His left upper limb had no fixed deformity except in the hand, but it did have some purposeful active movement and particularly fine control over his left index finger. He had no independent mobility.

Initial Video Interpretation

The pre-intervention school video showed that Alan was very interested in his surroundings and in interacting with other people. He was not overly fond of performing or using switches or the computer in front of other people: staff usually needed to hide or be out of sight while he was using his switches. The videos show he was able to demonstrate anger, happiness and unhappiness using vocalisations, facial expression and finger movement. In the videos, his eye pointing was not consistently effective nor did he have a yes or no response. Often staff made choices on the basis of preferences from normal daily routines. Alan interacted well with his mother at home over a range of daily life activities as well as computer and switch use. He used a range of switch operated toys, computer and some environmental control.

School and home settings

Alan was initially in a class of pupils who had no independent mobility and severe learning difficulties. His class teacher at this time was keen on promoting use of technology and he was offered environmental control and computer work on a frequent basis. Prior to the start of the Smart Wheelchair project, he was moved into another classroom grouping with a new classroom teacher. The new teacher had teaching and administrative duties and was in the classroom four days out of five in the week from January 1992. The school was open all 52 weeks of the year and she did not have leave at the usual school holidays, but had to use her 13 weeks holiday intermittently throughout the 52 week year. The classroom staff in this particular school also have holiday entitlement taken any time throughout 52 weeks in the year and as a result, continuity of Smart Chair use was difficult to achieve. Alan's classroom environment was small and cluttered but there was a shared, more expansive area outside it and the school gym was also available for use. The classroom team were particularly keen that Alan's chair should be used in bus outings and trips to the local library, shopping centre and seaside promenade were frequent outings for Alan.

Alan's house had a large lounge/dining room area with double doors opening into a hall leading through to his bedroom. The house was sufficiently large for some Smart Wheelchair use.

Aims and aspirations

General Educational Aims

- to develop Alan's concentration, attention and problem solving skills in functional situations and to improve his ability to ignore distractions
- to offer a wider range of situations where Alan could actively learn to problem solve
- to use switch-operated computer software in his own time without adult intervention, further encouraging increased attention scan, fixation and tracking skills

Communication and socialisation

- to further develop Alan's ability to communicate his needs, feelings, wants, likes and dislikes
- to develop expectation that his initiation and communication would elicit a response
- to extend his choice making from using concrete objects to using pictures or photographs
- to develop the use of eye pointing
- to develop the use of his left hand and index finger for communication
- to investigate and establish the suitability of a communication aid
- to encourage use of the pointer board when making choices
- to encourage turn taking
- to establish and develop the level of Alan's verbal comprehension

Functional mobility

- surprisingly, the staff had no specific aims to develop Alan's mobility

Physical and life skills

- to encourage the range of positions recommended by the physiotherapist
- to maintain and increase the range of movement available to Alan and integrate it into natural situations and activities throughout the day

Chair, seating and controls design

Alan's seating proved to be the biggest problem in setting up the Smart Wheelchair. He did not have a manual wheelchair and therefore did not have an effective seating system suitable for the Smart Chair. The Bioengineering Centre at Princess Margaret Rose Hospital designed and manufactured a complete custom-made seating system for his Smart Chair.

In addition, a lot of thought went into Alan's switching. He had difficulty both in targeting and releasing ordinary hit switches and his most reliable movement was bending and straightening his left index finger. He had used a Mercury tilt switch to detect this movement but the tilt switch was also dependent on the position of his arm in space and if he rotated his arm or moved it around, the switch would operate in error.

Instead, CALL designed a finger switch to detect flexion and extension of his left index finger regardless of its position in space. The switch consisted of a hall effect switch and magnet mounted on two rings located on the first two segments of his finger. When he straightened his finger, the magnet was moved close to the detector and the switch operated. The system worked well, but the rings were not particularly comfortable and sometimes slipped around his finger. The electronics were stitched to a cotton glove and this second version was more reliable and comfortable.

Using the Smart Wheelchair

Introduction

Alan's first sessions in January 1992 were designed to introduce the chair slowly. He sat with his helper in the chair, and was shown how to make it move using the finger switch and *Timed* control. He appeared enthusiastic and motivated so the team moved on quickly to give him control over driving his chair solo within the first week of use. He demonstrated understanding of cause and effect with the switch and the motion and his mother reported vocal and facial reactions to talking about the chair at home. Although his mobility was limited, he explored every possibility of it by driving around, stopping and looking for some time at quite simple everyday objects, before moving on. He showed previously unknown assertiveness by refusing to move until staff moved away from his chair. Alan's ability to explore all the aspects of a new tool and develop strategies for dealing with problems and limitations was to be repeated many times throughout the project. When 'Bump and Turn' was introduced in mid-February he showed the same ability to explore and assimilate the uses and limitations of the new tool. (On one later occasion Alan managed a complete circuit of the school in 35 minutes, bumping and turning through seven doors: his teacher counted 26 switch operations during a five minute period of time. This was not the result of random switch operation: he stopped once to watch a pupil outside for approximately two minutes and again to listen to a radio for four minutes.)

Communication

Alan used his finger to initiate conversation, and by linking it to the chair's movement he could do both at the same time: if he stopped to talk and then pointed his finger, he would immediately move away and his attempts to call for help moved him even further away. To avoid this frustration staff would offer him a choice of using his switch to activate a 'bleeper' when he wanted to communicate or drive the chair. The bleeper was also introduced into classroom activities when Alan was not using the chair and he used it to initiate a conversation with other pupils.

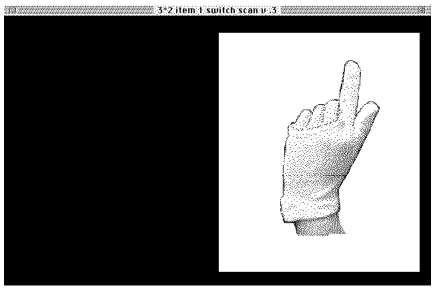
Continuity

In February, March and April the Smart Wheelchair Project key person in the school was seconded out of the school and the consequent lack of support at this early stage in the project, plus staff sickness, led to a break in Alan's chair work. Despite these interruptions in chair use, Alan did not seem to lose interest nor did his abilities regress. Alan's key worker left at the end of May 1992 and again there followed a period when his class teacher was out of school and no chair work was done.

Combining mobility and communication

To provide Alan with an independent means of moving and communicating, a 2 choice scanner was designed and built using HyperCard on an Apple Macintosh PowerBook. The team chose to build a system from scratch rather than use an existing system such as LightTalker or the 'Words+ Talking Screen' software package because the specification called for just two choices (he had never used a scanner before). It also called for digitised images of the wheelchair (below, left) and his assertion finger (below, right) as visual cues, rather than icons or symbols (although we hope to use the system to move to a symbolic system); and with digitised auditory cues to 'move' or 'talk'. The digitised visual and audio cues were used to reinforce feedback because very little was known about Alan's visual perception.

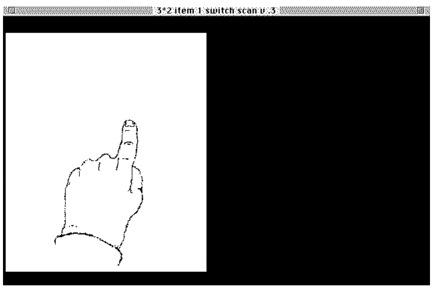
Wheelchair indicates 'move?'



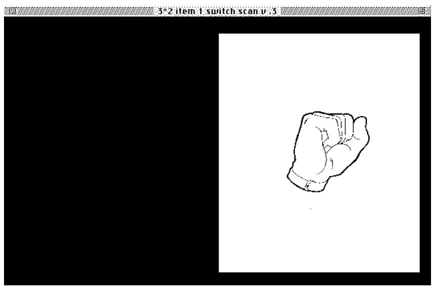
Finger indicates 'speak?'

On choosing 'move', the computer confirmed by saying 'move me forward' and instructing the chair to move. The chair responded by moving, confirming via the speech synthesiser. On choosing 'talk', a digitised recording of his bleeper would sound. By the end of his first session, he was moving and 'talking' appropriately.

Two choices was obviously limiting so the scanner was extended to provide three movement choices: forward, left and right movement; and three 'talk' options "yes", "no" and "I want to talk". The new selections were represented by animated line drawings of a moving hand, and line drawings of a hand fingering Makaton symbols (see below).



'Move forward'



"Yes"

Although his mobility was still crude, it was functional: his mother reported a 45 minute manoeuvre for Alan to reach the kitchen and collect his drink. He showed humour and strategy with his limited set of communication phrases, playing communication games with his teacher by calling her over saying he wanted to talk, sending her away again when she arrived, then calling her over again. This subtle and playful use of his extremely limited communication messages revealed aspects of his personality which were previously either impossible or at least very difficult to observe. Planning and executing such games shows an ability to construct and execute quite complex sequences of actions, while the nature of the games shows some grasp of language and its use as a means of social intercourse as well as information passing.

Alan's Smart Wheelchair and seating system was destroyed in an unrelated fire at the school in July of 1993 and work stopped. In March 1994 (three months after the evaluation ceased) the local authority agreed to replace the chair and it is now being manufactured. In the interim the school tried an ORAC communication aid but this was not successful. The team felt that this was because the minimum number of scanned options was eight, and the lack of auditory feedback. Therefore when the new chair is ready Alan will start off with the six-choice CALL scanner, and then transfer to either *Ke:nx* or *Speaking Dynamically* also running on the PowerBook laptop. In December 1994 Alan will be 19 years old and will leave school. He has a place at a local Day Centre and will take his new Smart Wheelchair with him.

Post-project Profile

Personality and cognitive state

Alan's post-intervention profile describes him as a sociable and lively young man. His teacher and mother feel he is much more assured and confident since he has been using the Smart Wheelchair. He is persistent: if there is something that he needs he will shout for it for an hour or more. He is still distractible but this depends on the activity and his interest in it. His main motivation and interest continues to be people: if left alone in his Smart Chair he can lose interest after a time. However, the incidence of these day-dream periods are thought to have decreased. One major change recorded by his Profile is in inquisitiveness and exploratory behaviour. It is not clear whether this is a new skill developed by chair work, or whether the Smart Chair has just enabled Alan to show his previously latent abilities. His exploration occurs on several levels: moving around the school examining classroom objects and people; attempting to operate other technology such as a hi-fi unit at home; as well as exploring the functions of his switch, scanner and Smart Wheelchair. He has developed friendships with specific classmates, vocalising with them, making eye contact and turn taking.

Vision

The profile records that Alan has established object permanence. He will look for lost objects and play hide and seek with Mum at home.

Hearing

There was no reported change in Alan's hearing.

Expressive communication

His teacher reports a mixture of eye contact, eye pointing, gestures, vocalisation, body language as well as his voice output system. He will initiate conversation with peers and adults. Classroom staff feel his eye-pointing is good, but therapists describe it as inconsistent. Alan still does not have a consistent yes/no response.

Receptive communication

Alan recognises the sound of his own name and can identify other people by name. He recognises and recalls familiar objects and routes when driving. He is socially aware and appears to respond appropriately to humour and emotion.

Education

His teacher reports that he is beginning to develop strategies and problem solve when in difficult situations such as manoeuvring through doors. He shows similar skills when playing games with his communicative messages. This extends to non-verbal interactions, where he will knock things on to the floor at home, waiting until they are picked up, only to knock them down again. He has good long-term memory for locations, people and events.

Physical mobility skills

Alan's gross motor skills remain unchanged although his mother feels that his head and trunk control has improved. She also thinks that his left arm is more controlled and accurate when targeting. Pre-intervention he has no functional mobility at all: his mobility is vastly increased through the Smart Wheelchair in school and in his rare use of it at home.

Long term process measures

Alan's Continuity Chart illustrates the pattern of Smart Wheelchair usage and changes in control and mobility skills throughout the intervention.

Opportunity for practice varied quite considerably throughout the project: at the start he was using the chair every day for long periods, but this reduced as time passed. This pattern was the opposite of the experience with some of the other children, whose chair time tended to *increase* along with skills and independence. Staff turnover, illness and holiday periods also interrupted Alan's progress, sometimes for weeks at a time.

Despite the irregular practice, the lower section of Alan's chart shows that he made steady progress in his control of the chair, starting with forward control only and finishing up going forwards, left and right. One constraint upon his development was his speed of progress which outstripped the technical team's ability to create new and more powerful systems. The Milestone record shows how the staff tried to integrate Alan's mobility into the curriculum, using a mix of one-to-one and group classroom-based activities, as well as class visits outwith the school.

SequenceView Analysis

Alan's pre-intervention profile describes a person with quite severe physical disabilities, who is sociable and inquisitive but whose cognition and understanding is difficult to assess. Alan's school staff and parents had a number of aims for his involvement in the project, mainly centred around interaction, communication and understanding. Specific areas included developing concentration; attention; problem solving; and the use of consistent communicative responses and initiations. One of the main areas of difficulty was in assessing Alan's capabilities and the inconsistent opinions given by staff regarding Alan's eye-pointing, for example, illustrates this. In general, assessment of Alan's understanding, perception or communication in either clinical or functional situations was compromised by his physical involvement and a lifetime of passivity. It is interesting that mobility was not identified as an aim in itself, possibly because it was thought to be an unrealistic option for Alan.

The *SequenceView* analyses were performed to quantify aspects of Alan's communication in a broad sense: to measure his ability to interact appropriately in functional situations. The *SequenceView* plots therefore record Alan's initiations using vocalisations, gesture, eye-contact as well as his switch. His communication partners are people and also the Smart Wheelchair.

Pre-intervention video analysis

The pre-intervention video lasts six minutes and was taken when Alan was in a swing in the gym. He is unable to either move the swing himself or to indicate when he wants it moved, but he does express enjoyment and interest. At one point his mind appears to wander and he stares fixedly at the rope holding the swing. The figures support the subjective interpretation of a person unable to exert control: Alan initiates (using gesture of facial expression) only 8 times in six minutes, and his physiotherapist initiates 56 times. He responds to these initiations, but accepts his passive role in the interaction because he has no other choice.

Post-intervention analysis - mobility sequence

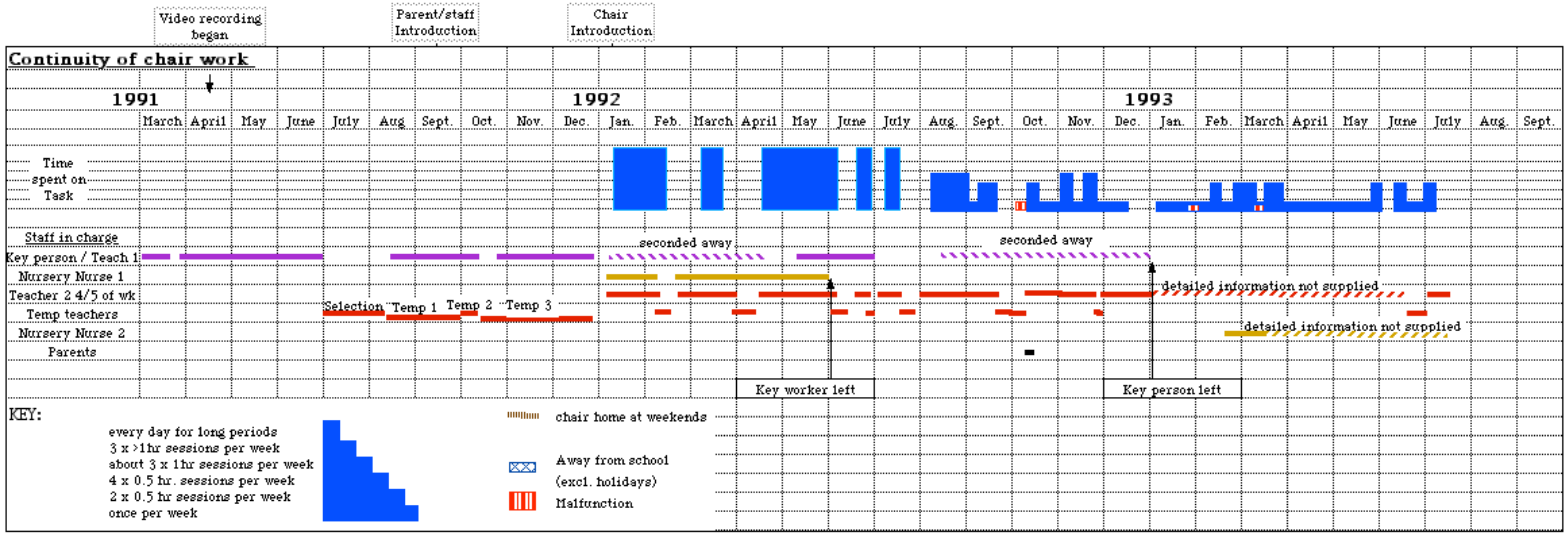
In this sequence Alan is in school, in a relatively cluttered classroom. He is using his finger switch to control his combined wheelchair controller/communication aid giving him six mobility and communication options. In this sequence he is using the system primarily to move around and his 36 initiations are directed at the chair and his teacher. The ratio of initiations pre- and post-intervention give a clear representation of his improved assertion when in the chair: 8 to 36. They are almost wholly initiations using his finger switch. The response from chair and teacher are immediate and appropriate, contributing to the even spread of interactions from Alan throughout the 5 minute sequence which illustrates Alan's concentration and attention to the task. The main communication partner is the wheelchair, who 'initiates' (using visual and audible prompts) 62 times by offering motion or speech choices and reporting collisions.

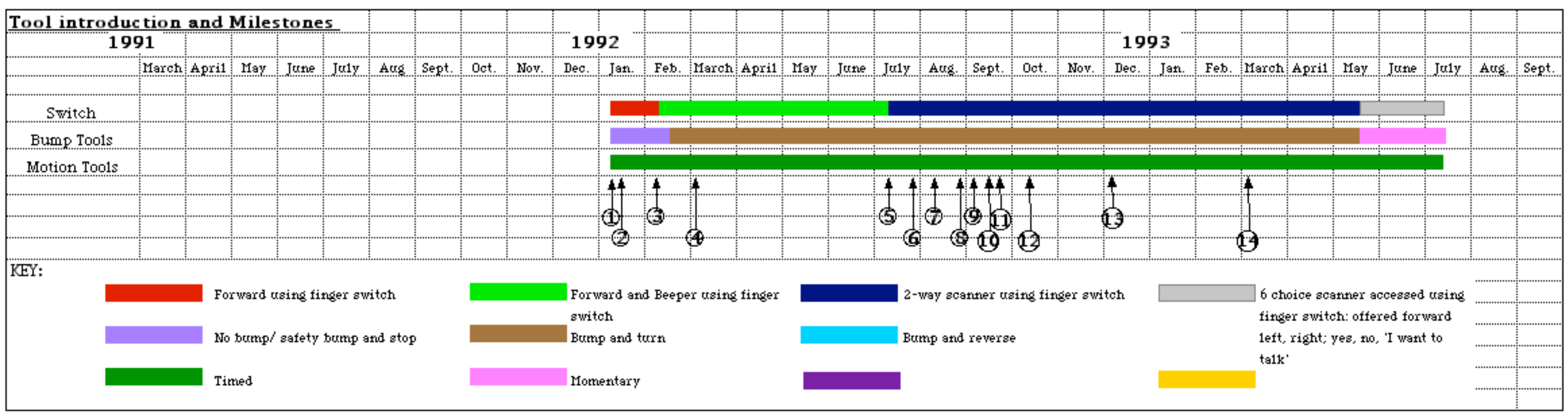
Post-intervention analysis - 'talk' sequence

This 5 minute recording is a little later in the same session, when Alan is interacting with his teacher using the 'talk' options on his system. Again, the number of initiations pre- and post-study reflects improved opportunity for control: 8 to 24. The initiation figures also show a more equitable balance of power in the conversation between Alan and his human partner: 8/56 pre- compared to 24/22 post-study. The pattern of initiation-response-initiation between Alan and his teacher shows that turn-taking is working well. Again, the 55 machine initiations represent prompts from the scanner.

Overall, the analysis support the observations gathered by the post-project profile, of a young man with greater control over his environment and social circle.

Alan


Video recording began
Parent/staff Introduction
Chair Introduction
Continuity of chair work
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Time spent on Task
Staff in charge
Key person / Teach 1
Nursery Nurse 1
Teacher 2 4/5 of wk
Temp teachers
Nursery Nurse 2
Parents
seconded away
seconded away
Selection
Temp 1
Temp 2
Temp 3
detailed information not supplied
detailed information not supplied
Key worker left
Key person left
KEY:
every day for long periods
3 x >1hr sessions per week
about 3 x 1hr sessions per week
4 x 0.5 hr. sessions per week
2 x 0.5 hr sessions per week
once per week
chair home at weekends
Away from school
(excl. holidays)
Malfunction


Tool introduction and Milestones
1991
1992
1993
March April May June July Aug Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept.
Switch
Bump Tools
Motion Tools
1 2 3 4 5 6 7 8 9 10 11 12 13 14
KEY:
Forward using finger switch
Forward and Beeper using finger switch
2-way scanner using finger switch
6 choice scanner accessed using finger switch: offered forward left, right; yes, no, 'I want to talk'
No bump/ safety bump and stop
Bump and turn
Bump and reverse
Timed
Momentary

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Progress Chart (blank side, should be even page number)

KEY TO MILESTONES

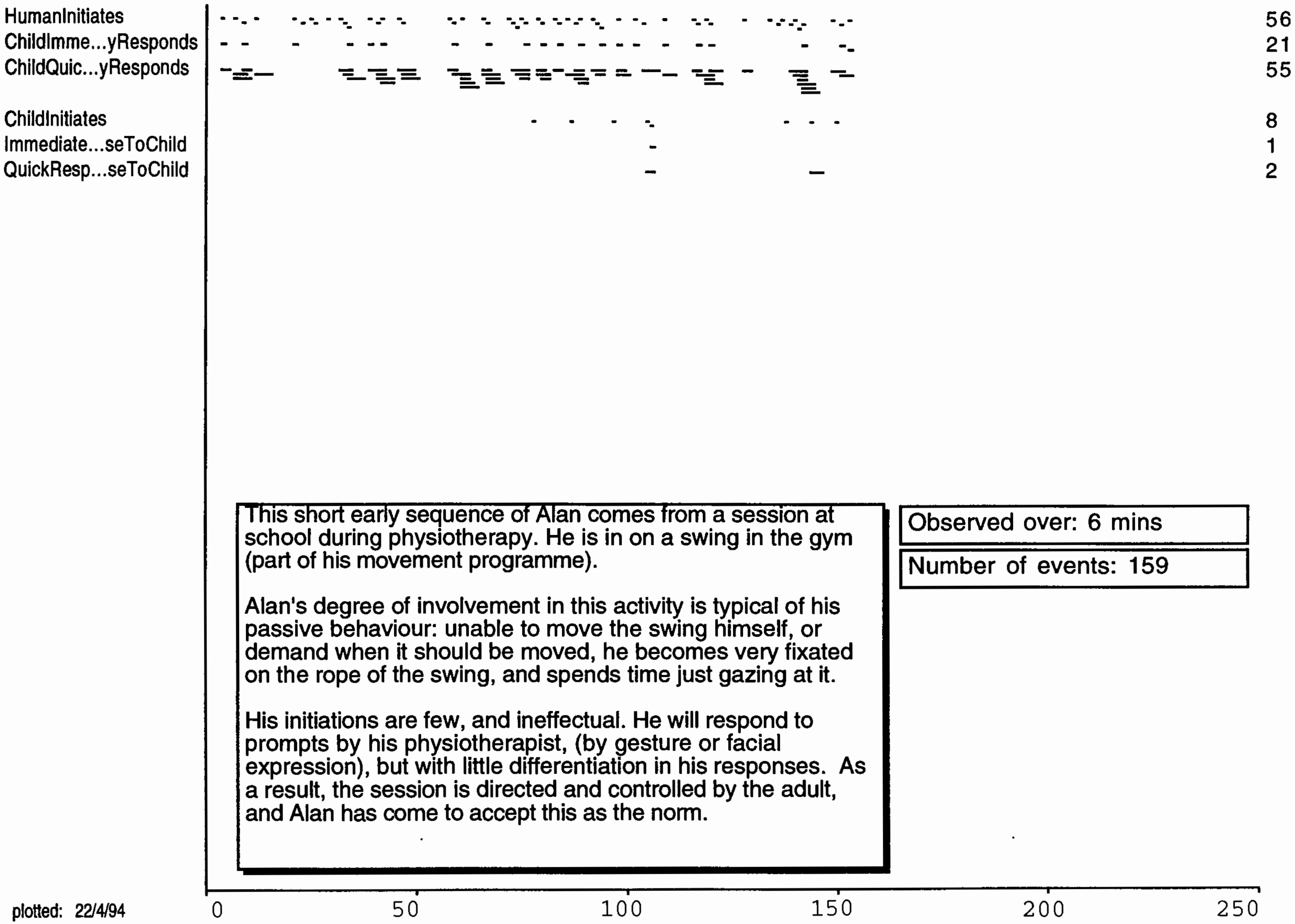
1. Alan goes solo; he shows understanding of cause and effect.
2. Mum reports vocal and facial reactions to talking about the chair.
3. A choice of beeper is introduced to [indicate] communicative intent. Alan attempts to initiate a conversation with another pupil. He drives past Snoezelen door of the room where the rest of the class are, and is extremely cross [to have missed the door], leaning out of the back of chair until he is turned back in that direction.
4. Alan is extremely cross for the rest of the day after his chair fails halfway through a session.
5. He is definitely making appropriate choices when using the scanner for the first time, although probably using auditory scan rather than visual scan.
6. He works well for 10 minutes, choosing 'move' nearly all the time.
7. The original intention was to allow use of the chair for a short time before connecting the scanner, but once in the chair he uses the switch,bumps and turns through a doorway and drives away. Tally count is 26 switches in 5 minutes during 35 minute session as he does circuit of school. He uses Bump and Turn to go through 7 doors; stops twice to watch a pupil outside (2 minutes) and to listen to the radio outside the cleaners' room (4 minutes).
8. After a visit is made to Cramond, Alan’s teacher reports "...Alan operated his switch many times. We were not stationary for longer than a minute at a time".
9. “Alan is impatient to get into his chair today, waving his finger and complaining until seated and ready to go. When he chooses ‘bleep’, I interact with him, using various activities - book, pictures, musical instruments, colour boxes etc. Alan continues to choose ‘bleep’, but when he changes to ‘move’, I cease the interaction and allow him to move freely."
10. "On a bus trip to Winter Gardens (10 minute drive), Alan spends the first 6 minutes gazing out of the bus windows, then uses his switch to operate ‘beep’. I chatted to him for the remainder of the journey when he used the beep several times."

    "In a large greenhouse, he twice moves to stop in front of a large tree and spends a long time looking at the leaves. He then moves forwards again to reach the pond and spends the rest of the time looking at the fish."

    "He chooses to beep 11 times, but moves only 5 times. There is a lot of verbal expression and ‘looking at’ activities which I had brought for discussion. He obviously wants to keep the interaction going."
11. "Alan chooses ‘move’ nearly all the time. He moves out of the classroom. Luckily the chair is in line with the door of the physiotherapist’s room which is open. He moves through the area and into the physiotherapist’s room (a consistent choice of move). Once in the room he sits for some time, looking around and in the full length mirror. After about 10 minutes, he calls me to come and see."
12. Mum asks Alan to drive through to the kitchen if he wants a drink. She can hear him moving about the hall, bumping and turning and finally, 45 minutes later, he appears in the kitchen. When asked if he wants a drink, he laughs and takes it happily.
13. "Alan is clearly watching the scanner and waiting for the sign to come up that he wants to choose."
14. "Alan moves from one end of the red carpeted area to the other, mainly using the ‘move’ switch, only using ‘beep’ 3 times. He is relaxed and interested in his environment, with lots of smiles and verbal sounds when he uses his switch. He shows signs of great pleasure and enjoyment. We use the colour box for conversation when Alan chooses ‘beep’ (when told he only has a couple of minutes left, he switches 3 times, immediately laughing and giggling)."

    "In the library, he switches the chair on and sits for a good ten minutes looking up at a rotating fan on the ceiling. This holds his full attention. He uses ‘bleep’ (talk) on several occasions."

Alan (Pre-study) 17/4/91



This short early sequence of Alan comes from a session at school during physiotherapy. He is in on a swing in the gym (part of his movement programme).

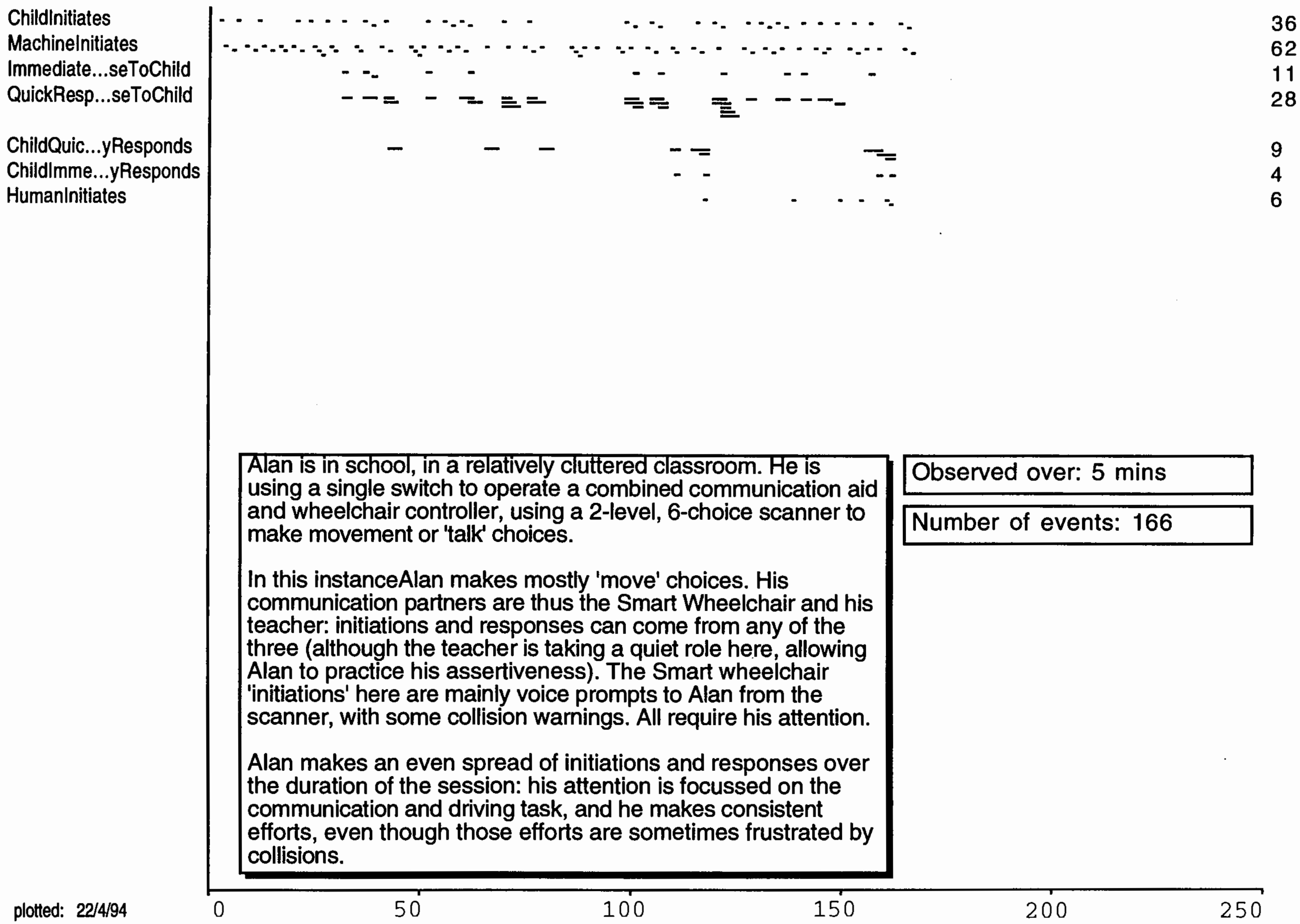
Alan's degree of involvement in this activity is typical of his passive behaviour: unable to move the swing himself, or demand when it should be moved, he becomes very fixated on the rope of the swing, and spends time just gazing at it.

His initiations are few, and ineffectual. He will respond to prompts by his physiotherapist, (by gesture or facial expression), but with little differentiation in his responses. As a result, the session is directed and controlled by the adult, and Alan has come to accept this as the norm.

Observed over: 6 mins

Number of events: 159

Alan (Post-study) 20/5/93a - predominantly mobility acts



Alan is in school, in a relatively cluttered classroom. He is using a single switch to operate a combined communication aid and wheelchair controller, using a 2-level, 6-choice scanner to make movement or 'talk' choices.

In this instanceAlan makes mostly 'move' choices. His communication partners are thus the Smart Wheelchair and his teacher: initiations and responses can come from any of the three (although the teacher is taking a quiet role here, allowing Alan to practice his assertiveness). The Smart wheelchair 'initiations' here are mainly voice prompts to Alan from the scanner, with some collision warnings. All require his attention.

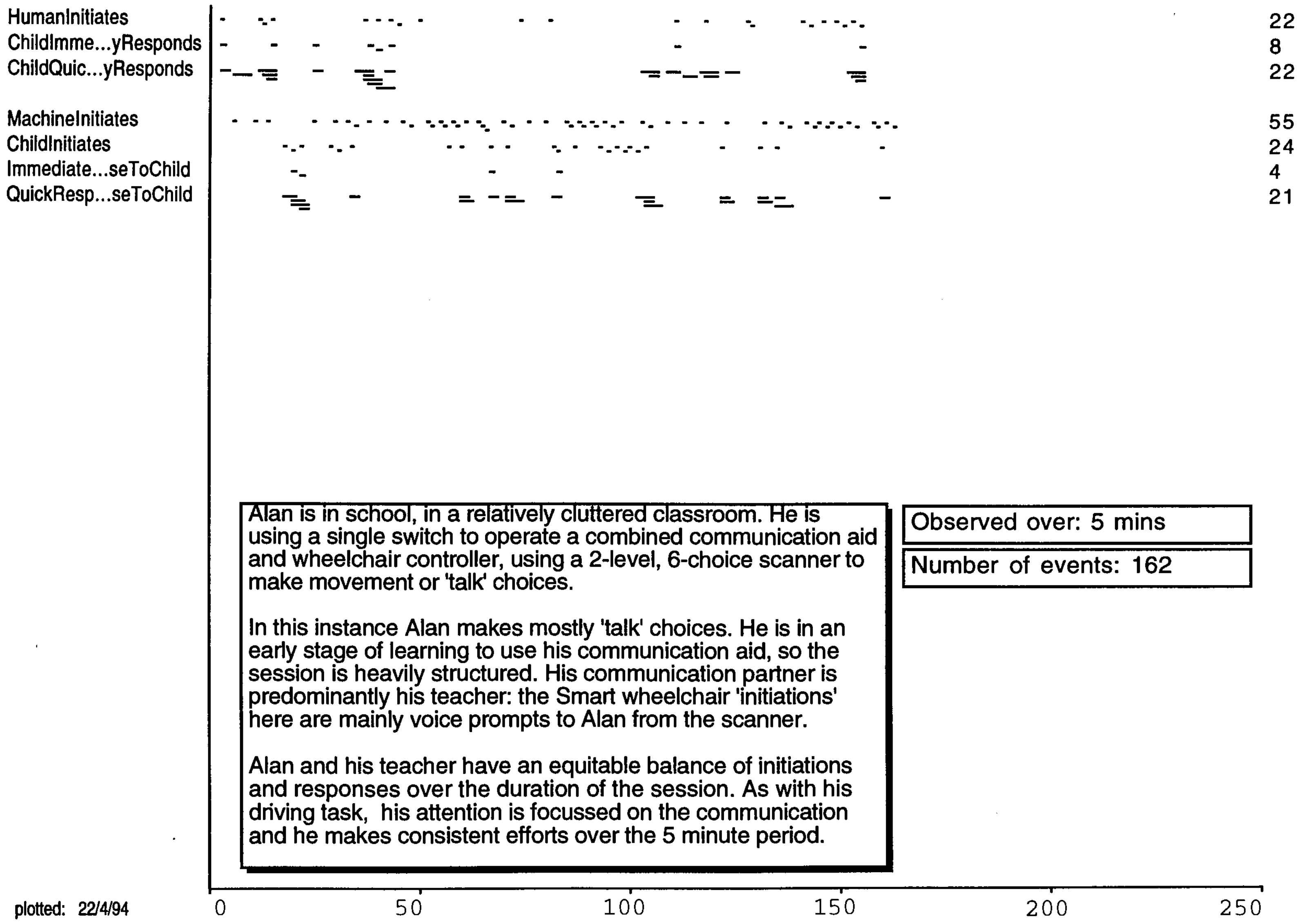
Alan makes an even spread of initiations and responses over the duration of the session: his attention is focussed on the communication and driving task, and he makes consistent efforts, even though those efforts are sometimes frustrated by collisions.

Observed over: 5 mins

Number of events: 166

plotted: 22/4/94

Alan (Post-study) 20/5/93 b - predominantly talking



Alan is in school, in a relatively cluttered classroom. He is using a single switch to operate a combined communication aid and wheelchair controller, using a 2-level, 6-choice scanner to make movement or 'talk' choices.

In this instance Alan makes mostly 'talk' choices. He is in an early stage of learning to use his communication aid, so the session is heavily structured. His communication partner is predominantly his teacher: the Smart wheelchair 'initiations' here are mainly voice prompts to Alan from the scanner.

Alan and his teacher have an equitable balance of initiations and responses over the duration of the session. As with his driving task, his attention is focussed on the communication and he makes consistent efforts over the 5 minute period.

Observed over: 5 mins

Number of events: 162

4.6 Summary of Outcomes across Cases

We have distinguished between two different perspectives on assessment for mobility - single episode ‘driving test’ styles of assessment, and the incremental gathering of evidence we have employed during the project. In this section, we suggest an approximate relationship between the two techniques, and plot the achievements of the children against this benchmark.

Earlier, we said that other testers and researchers have set out stages which form an idealised progression from no driving skill to full competence, and we return to these now. They were

Simple moves	being able to make the chair move
Stops	being able to stop the chair appropriately
Straight line	being able to keep the chair moving in a straight line
Pointing	using the chair to point to an object
Twin curve	steering the chair around an S-shaped curve
Left sharp turn	90˚ turn to the left
Right sharp turn	90˚ turn to the right
Multiple sharp turns	sharp turns to the right and left consecutively
Reverse	being able to reverse the wheelchair safely
Three point turn	changing the direction of the chair in a confined space by reversing and turning

These stages can be related to the performance gains indicated by progressive mastery of particular wheelchair tools in functional settings: hence the importance attached to tool changes and functional observation during the long-term process measures.

Simple moves: recognition of the function of a control, and being able to select it (but not necessarily stop in time or plan starts appropriately)

Stops: ability to stop appropriately. (In some children’s case, stopping is left to the chair. For collision avoidance, the child’s task turns into one of planning an appropriate start time. For other children, mastery of stopping implies improvements in physical timing and control release, whilst in some cases the achievement may be due to better concentration or attention)

Straight line moves: achieving this goal implies mastery of the two skills above.

Pointing: implies control over turning. Ideally, this should be assessed as part of the learning of a second or further degree of freedom, when the child is using both forward and turn control. However, for children who might have to use scanning systems, but are not yet able: or for children who might eventually use a second switch, but may need prior training on control during turns, this assessment might be carried out with just a single switch: careful choice of curriculum context can make ‘spot turns’ functionally meaningful.

Twin curve: implies at least three channels of control. Conventional tests were devised with analogue controls in mind. Augmentative mobility users may be operating switched or scanned systems in which curve control is impossible. We therefore consider the person competent at this task if they can negotiate paths with both left and right obstacles (which is, after all, what the test was intended to approximate).

Sharp left turn, or sharp right turn: unlike pointing, this test combines the ability to line up on an offset target, turn towards it, and set off. Like the test above, it is an abstraction of a real world task. We have real world observations to hand, and take this skill to be attained if the child can navigate through a doorway. (Note that whilst left and right turns are very desirable, if a child cannot make a 90 degree turn in one or other direction because they have only two degrees of freedom, we can still assess them as functionally able if they can make a 270 degree turn using the control they have. In terms of planning, estimation, timing, and perceptual-motor coordination skills, and the functional outcome, it matters little which way round you go.)

Multiple sharp turns: as with twin curves, multiple turns can be assessed by real-world performance in constrained environments. Fortunately, most environments provide many such test situations.

Reverse, and three point turns: This requires four degrees of freedom, and the ability to see behind the chair. Some children have eventually shown this degree of skill. However, others may never achieve accurate reverses, because of their inability to see rearward targets. For such children, the Smart Wheelchair can offer supplementary tools - pre-stored reverses, for example, or line-follower aid. In this case, the test becomes one of appropriate choice and use of these tools. (This study has not yet explored training for such movements: we believe that when some of the children reach skills plateaux in coming years, these emerging tools should form the next stage) .

We should stress again that there cannot be a one-to-one correspondence between driving tests and functional stage assessments, and that therefore the summary results overleaf are indicative.

We also claim wider social, educational, and communicative developmental benefits. Bringing these together in ways which help to make meaningful comparisons is more problematic, since the range of children involved is so wide: we would not wish to make any statistical claims. However, we *can* give an impression of what has been achieved, sufficient to set against the main environmental variants, which are time for practice, and fragmentation.

Summary of outcomes, sorted by total practice time

Name	David	Alan	Graeme	Sara	Jack	Stephen	William	Cameron	Adam	Ross
Total time on task (hours)	1087	172	83	75	37	34	26	20	19.5	11
Disruptions										
lack of continuity					√	√	√	√	√	√
illness				√			√		√	√
staff/class changes during intervention	√	√	√	√			√	√		√
Mobility										
Three point turn	●									
Reverse	●									
Twin curve/multiple turns	●	Δ	*	*	Δ					
Sharp left/right turn	●	●	Δ	*	●					
Pointing	●	●	Δ	●	●	Δ	*	*	Δ	*
Straight line moves	●	●	●	●	●	●	*	●	●	*
Control over stops	●	●	●	●	●	●	●	●	●	Δ
Simple moves	●	●	●	●	●	●	●	●	●	●
Improvements reported										
Assertiveness/Motivation	good	good	fair	fair	fair	fair	mixed	mixed	fair	none
Concentration/attention	good	good	fair	fair	mixed	mixed	fair	mixed	fair	?
Communication	good	fair	slight	slight	fair	fair	fair	fair	slight	slight
Socialisation	good	good	?	mixed	?	mixed	fair	none	slight	?
Physical skills	good	slight	fair	mixed	fair	fair	slight	slight	mixed	?

Key (Mobility):
● = skill consistantly demonstrated
Δ = current therapy, improving
** = current therapy, mixed results*

Key (Improvements reported):

good	*consistent improvements against this child's baseline*
fair	*improvements recorded - occasionaly spasmodic*
slight	*some improvements, slow progress*
mixed	*improvements localised / poor transfer / inconsistent progress or regressions*
none	*no gains made*
regressed	*child now consistently worse against baseline*
?	*<no reports>*

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5. Discussion of Case Study Findings

5.1 Effectiveness of the Smart Wheelchair

The case studies indicate the breadth of areas of improvement which can come from improved mobility. They show how these improvements both *extend* into learning, play, communication and socialisation, and *depend* on being nurtured in such functional settings.

As far as the direct use of powered wheelchairs is concerned, our cases spanned children who used the Smart Wheelchair as an effective mobility training aid through to those who will, we believe, always achieve their mobility via augmentative controls, registering successes in both groups.

When introduced and exploited as part of an integrated curriculum, staff also reported significant improvements in children's social skills, and as a result of this, more opportunities for meaningful functional communication. When their circumstances were constructed appropriately, children took advantage of their opportunities to explore, and their inquisitiveness fed back effectively into their persistence in learning the necessary skills. Social and exploratory improvements both in turn open yet more opportunities to extend other curricular areas.

More directly, the video records show clear gains in the patterns of interaction both between child and human partners, and between child and chair control system. We feel confident that skills are being transferred. Moreover, close examination of the video sequences (both coded and uncoded) show changes in the interaction patterns of teachers to children, with less anticipation of passivity in the child on the part of adults.

The studies also reveal improvements in posture and physical skills.

None of the children appeared to suffer as a result of their chair work. The chair is safe in a supervised setting - no accidents took place in the three year programme to either the children, or their environment, or people in it. The newer tools are improving safety features further - soft bump and collision avoidance tools will further help allay fears for other children in crowded settings. We were also concerned that children might become overdependent, and reduce their efforts in other mobility acts. If anything the opposite effect was noticed, with children who had extended access to their chairs appearing to appreciate the value of independence more, and working hard to achieve it in other ways (an example being the young boy who began to try to operate his manual wheelchair after watching Smart Wheelchair work). Fears about poor effects on posture of long term chair work also proved groundless. In a number of cases, posture seemed to *improve,* possibly due to the active effort needed to control the chair: motor skills certainly benefited.

However, although nearly all children proved to be motivated by their experiences in the Smart Wheelchair, the spread of developmental gains was wide over our case studies. From the pilot studies, we had expected there to be individual differences, and were prepared for these to be quite subtle interactions between abilities, personality, and developmental stage. In the event, these individual differences did not seem to be the predominant feature determining progress.

When an able person learns a new skill, we know what to expect of them. Our own experiences tell us how long it takes to learn to spin a top, or ride a bike, or operate a word processor, or drive a car. We know, too, how much variation there is between people's abilities to learn. It appears to us that this understanding and the expectations which it should generate is somehow failing to be applied when planning learning environments for disabled children developing similar skills. Driving a Smart Wheelchair needs something of all of the abilities above: the reader should compare the opportunities for extended learning which some of our case study children have had, with their own skill learning experiences. We now turn to why this should be so.

5.2 Factors affecting Success

5.2.1 Environmental effects

There are many areas of interplay between development of specific mobility-related driving skills, and broader areas of education, which make it difficult to introduce tools like the Smart Wheelchair in isolation from other learning and communication aims and goals. Some aids (like spectacles) need little in the way of training. Others (especially complex augmentative systems) need careful introduction and a lot of practice. A Smart Wheelchair certainly needs practice. However, for that practice to be effective for children who are conditioned to failure, it must produce practical benefits for the child. These benefits need to be seen on a day-to-day basis: no-one will persist in using glasses if they are only available during practice sessions.

To make a system as complex as a Smart Wheelchair available to a child for extended periods means a commitment on the part of staff. This investment must also pay off for them.

In the event, the environmental differences between the case studies turned out to be the dominant factor in determining degree of success. Comparison of the long-term study chart show very large differences between the opportunities offered to children, both in terms of time-on-task, and the degree to which children's learning environments were tailored to take advantage of the Smart Wheelchair. In the best cases, children saw the Smart Wheelchair as a constantly available tool, used both at home, school and for supervised outings. In the worst cases, the Smart Wheelchair was used for occasional ‘sessions’ (in some cases only prompted by the appearance of the evaluator), unconnected with other activities. These differences strongly influenced the outcomes.

Of those children who had least opportunity to use the Smart Wheelchair, the project team felt most disappointed about Cameron (the very young child), and Ross, though for different reasons. In Cameron’s case, it was frustrating to see increasing reports of passive behaviour after his first teacher left, whilst a tool with the potential to reduce such passivity lay little used. It was also difficult to understand, since school staff felt the chair to be one of the biggest motivators for him. In Ross’s case, we clearly did not succeed in convincing the school team that the most value to be got from the Smart Wheelchair in his situation was not so much improved mobility (we could at best have only complemented his other evolving strategies), but in setting up structured exercises aimed at improving planning, symbol use, estimation, and other educational goals.

Any project-based intervention into day-to-day school or therapeutic practice, technological or not, will be at risk if the teaching team is not enthusiastic (or is constantly changing), or if the project is too novel to articulate with the design of the school curriculum. In Scotland, common curriculum guidelines are emerging for children aged 5 to 14 years, and these include children with special need. The clear implication for the Smart Wheelchair (and for other new technologies) is that work must now go into relating technological opportunities to these national aims, therefore enabling school staffs to specify and use them effectively. The Smart Wheelchair team have latterly put a large proportion of their resources into laying the foundations for such work, by producing and testing training materials; creating booklets of suggested activities; and proposing a pilot study into more formal links with the Scottish *5-14* Guidelines.

5.2.2 The need for a curricular base for dissemination of innovations

The Smart Wheelchair is by no means the only technological aid to learning or communication to suffer from patchy take-up because of different perceptions of the relevance to required and ongoing day to day teaching, learning and assessment activities. It is often claimed that identifying and promoting centres of excellence, and highlighting the activities of inventive teachers will lead to widespread adoption of those practices by osmosis. Our evaluation shows, as usual, that while some teachers and therapists are quick and inventive, and while some environments encourage their development, others increasingly see such efforts as standing apart from the demands already placed on them, and do not take up innovative practices. For busy teachers and therapists to see the relevance (or, in some circumstances, to legitimate the allocation of time and resources), there are two prerequisites: a curriculum structure into which the technology fits, and clear indications of how it contributes in ways which would otherwise be difficult, expensive, or impossible.

Fortunately, at the same time as CALL were developing and evaluating the first batch of ten Smart Wheelchairs, major changes in the Education system have been taking place. In England and Wales, these have taken the form of the introduction of the National Curriculum and its close Scottish relative, the Guidelines for the 5 to 14 Curriculum (which has come to be known as *5-14*). Recently, at a conference in Jordanhill College, Glasgow, a group of working parties reported on the adaptation of the *5-14* guidelines for children with special needs (*Support for Learning: 5-14*). It is now widely recognised that the principles and structures offered by *5-14* bring much of potential benefit to special children. The teaching and therapeutic community is also aware that staff will need a lot of support in the years to come as the curriculum proposals move from statements of principle and approach to classroom practice.

This means that we are now in a position to make a contribution to more structured dissemination and use of the techniques pioneered in the Smart Wheelchair projects. The Smart Wheelchair is a maturing piece of technology, already in use in several schools. The *5-14* curriculum and the guidance offered by the working parties offer a framework recognised by teachers, and enthusiastically demanded by parents, into which the Smart Wheelchair's curriculum developments can fit. The SOED Inspectorate helpfully believe that *5-14* is inclusive: **all** children lie within the framework.

We are therefore undertaking a project which will apply our experiences in developing and evaluating the Smart Wheelchair to the production of both general and specific guidelines and exemplars for teachers and therapists wanting to use the Smart Chair in the *5-14* curriculum context. The general booklet will help teachers who have no experience of the Smart Wheelchair to decide if such a tool would be useful to their child. The specific materials exemplify how, at a practical level, curricular goals may be achieved.

This is an enabling project, which itself will lead to and underpin other activities. The most direct will be to use the materials to support the broadening base of Smart Wheelchair users, testing and refining them as necessary. The second aspect we expect to follow up will be the relationship between the *5-14* Smart Wheelchair materials, and those needed to support the National Curriculum in England and Wales.

5.3 Unfulfilled Goals

The evaluation project failed to address the use of the Smart Wheelchair in more advanced educational areas. We had hoped that at least one of the children would have been able to use the chair as part of a curriculum which included LOGO-like micro worlds for learning estimation, planning skills, and perhaps some number work. In the event, the aims for the children were much more focussed on early learning, mobility itself, and communication: the wider application of the Smart Wheelchair remains untested.

We believe that part of the reason for this is that despite the success of exploratory microworlds in mainstream schools, they are relatively novel in special education. It remains one of our goals to at least bring an awareness of the benefits of some of the established LOGO methodology and materials into the decision-making processes which define the curriculum for a Smart Wheelchair -using special child. We hope to do this in our current pilot project on *5-14* Curriculum and the Smart Wheelchair.

There was also little opportunity to try more complex integrated systems involving either commercial communication aids or links to computer-based-learning (with the exception of the young man who was moving from chair control to mixed chair and communication, although even here, the systems were all produced by the project team, and did not include external aids). The mix of children and the aims defined for them precluded such work during the present project. However, we feel strongly that this area will need attention in the future, probably even for some of our current project cases as their needs change.

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6. Products: Material and Training Outcomes and Product Testing

In our project proposal, we said this about the outcomes and products we envisaged

> *"The project worker will be responsible for the generation of both tangible project products, and intangible (but vital) influences during project development.*
>
> ***Dissemination Products***
>
> *The most important product will be a series of documents which will inform and guide teachers, therapists, and others in how to set up, adapt, and use the chair in a variety of curricular, training, and assessment sessions.*
>
> *Related to the production of these written materials will be the design and running of a short series of seminars on the use of the chair.*
>
> *Since we believe that the weakest aspect of much Research and Development work is the dissemination of results in a practical and concrete form to potential users, we rate the production of literature and courses highly in priority. We shall also be seeking effective ways of dissemination through appropriate networks, in the belief that a combination of direct influence (through the project schools); course and seminar attendees; and distribution of practical guides through existing networks, form a more powerful approach to dissemination than through academic papers or journal articles (though these have their place).*
>
> *One of the tasks of the team is to determine what literature is needed. However, we presently believe that the documents needed include:*
>
> - ***A Brief Introduction to the Smart Wheelchair***
>   *an overview which can serve as introductory course notes, and to inform new enquirers.*
> - ***A Practitioner's Guide to Initial Assessment of Children and Adults***
>   *highlighting how to determine if the chair might be of use, what aims might be practicable, and how to find out what adaptations might be called for.*
> - ***The Roles of the Smart Wheelchair in Teaching and Therapy***
>   *a detailed handbook which relates the chair facilities to the aims and objectives of teachers and therapists involved in planning, intervention, and devising observations and assessments in the areas of interpersonal communication, special educational curricula, and mobility training.*
>   *This book will be the central product, and will include case descriptions, suggestions and examples, and distilled results of observations made during the wheelchair evaluation period. In particular, it will emphasise the profile of use and adaptation needed during a child's development of skills, and will seek to avoid inappropriate static models of curriculum design by stressing the potential for observing progress and responding to observed changes.*
> - ***Setting up the Smart Wheelchair***
>   *hints, tips, and procedures on*
>   *- seating,*
>   *- switch and other control positioning,*
>   *- choosing tools.*
> - ***The Wheelchair Playbook***
>   *a collection of user-community-generated ideas on wheelchair use: introducing the new child, activities for play and exploration, motivation, communication.*
>
> *The researcher will also be responsible for field trialling the first two of the three other documents below (which will be produced by the technical team), and for reporting on their usability, quality and accuracy:*
>
> - ***The Smart Wheelchair Technical Manuals***
>   - *User Manual*
>   - *Technical Setting Up*
>   - *Maintenance Manual"*

This section discusses how these aims have been met.

6.1 Training and Dissemination: Courses and Associated Materials

Appropriate support documents and courses have both been produced, and the materials are included as Annexes to this report. We have:

- run **introductory courses in the CALL Centre and in schools** for project teachers, therapists and parents, backing these up with appropriate teaching materials (see below).
- run **awareness workshops** for the wider professional community in Scotland.
- mounted a **one day conference on the Smart Wheelchair**, with presentations by both the CALL team and teachers, therapists and parents.
- designed and run (with EEC help) **a five day, in depth course on how to use the Smart Wheelchair**, aimed at multidisciplinary teams: the first course was made up of teachers, speech and physiotherapists, psychologists, an engineer, and administrators.
- presented the Smart Wheelchair Project (both design and formative evaluation) at **national and international conferences**.

A summary of dissemination activities is given in **Annex 9**.

We have noted elsewhere in this report the problems of integration of the Smart Wheelchair into schools' curriculum. One implication of the solution we suggest (that of promoting the relationship of the Smart Wheelchair with the 5-14 Curriculum Guidelines) is that the materials we have produced will inevitably need recasting into that mould.

6.2 Materials for Teachers and Therapists

Undertaking the dissemination work above has allowed us to generate a number of introductory documents, each aimed at different audiences.

- **Introducing the Smart Wheelchair. Annex 7** shows a short form, intended for first-contact introductions.
- **Smart Wheelchair Training Pack. Annex 8** shows the materials for a full training course. This latter document (together with supporting papers and notes) serves both as general course material, and the basis for dissemination of information on specific topics.
- **Using Smart Wheelchairs.** To support these courses, and as outreach to those people not able to attend formal training or seminars, we are now preparing an informal book on the Smart Wheelchair (in press).

The team have completed these associated documents, which have been in use throughout the project:

- **Guides for Mobility Training and Assessment (Annex 5)**
- **Wheelchair Playbook (Annex 6)**

User Handbooks (Annex 4) and **Technical Documentation** have also been created and field tested.

We now realise that the issues raised by the use of the Smart Wheelchair, and the range of potential professional and parental readers, are too diverse to be served by a small number of all-embracing documents. We have therefore moved from writing monolithic descriptions to designing sets of smaller, reusable materials which can be drawn together to meet different needs. As a result, the training course shown in Annex 8 has been written in modular form. Together with the 'Guides for mobility training and assessment', sections of these training materials also satisfy some of our aims for what we had thought of as the 'Practitioners Guide to Initial Assessment'. Similarly, materials needed for disseminating information about the 'Roles of the Smart Wheelchair in Teaching and Therapy' are also contained in Annex 8, together with aspects of the 'Wheelchair Playbook'.

We are convinced that such modular material can also be delivered in interactive forms, and we are currently exploring how our paper-based resources can be embedded into multimedia hypertext formats, enhanced by video fragments from our extensive recordings of children in the programme.

6.3 System Effectiveness and Design Changes

A major part of the evaluation team's work was concerned with providing feedback from schools to the design team on the effectiveness of the Smart Wheelchair. In our proposal, we said of the formative role of the evaluator:

> *"As well as their role as co-devisor and tester of innovative programmes and assessments and producers of the written products [...], the researcher will be contributing in other ways:*
> - *as **progress chaser**, s/he will be the main link between design team and schools.*
> - *as **trainer**, s/he will be responsible both for keeping the school team up to date on results, and for designing the outreach exercise.*
> - *as **support for school**, s/he will reduce the disruptive effects on the schools of new, and probably unreliable, technologies and practices."*

The evaluator fulfilled these roles in each of the three schools, on a time-sharing basis. Balancing the roles of information-gatherer and detached analyst with those of assessment team member, supporter, trainer, and go-between is not easy: there are inevitable compromises. Helped by her feedback, many important design changes and refinements have been made to the Smart Wheelchair. These include changes to:

Bumpers

The collision sensors have two functions: to detect all collisions quickly, and to absorb the force of a collision when it occurs. There are bumpers situated at the front and rear of the chair, each consisting of three sensors mounted in foam (as opposed to 1 sensor in each bumper in the prototype: the use of several sensors for each bumper allows the software to make decisions about the angle of the collision). The bumpers are mounted on steel brackets bolted to the wheelchair chassis. The early chairs used pneumatic sensors for detecting collisions. These worked reasonably well and provided a good compromise between detecting collisions and absorbing the force of the collision. However, they were bulky, expensive to manufacture, and the evaluator reported reliability problems due to air leaks.

A second design was produced and fitted to 9 of the chairs. This again consisted of foam bumpers with sensors embedded into them but this time the sensors were strips of pressure sensitive material whose resistance decreased with pressure. This reduced the cost and simplified the design by:

- replacing expensive pressure switches with cheap electronics.
- replacing air tubes with single-strand wire.
- simplifing the foam covering of the sensors.

In addition the foam bumpers were fixed to the steel brackets with velcro, allowing the bumpers to detach from the frame if they became caught. This reduced the risk of tearing: the teacher could then simply fix the bumpers back in place.

While 'Bump and Turn' proved useful for giving single switch users the opportunity of crunching round their environment to explore it, as a functional mobility system it leaves a lot to be desired. A more useful 'Bump and Turn' tool would make use of the pilot's perceptions and skills by giving control over the distance reversed and the direction and angle of turn. This in turn would require the user to understand that the switch which previously moved the chair forward has now taken on several different functions throughout the bump and turn manoeuvre. Immediately after the collision the switch will move the chair away from the obstacle until released; then it is used to select either left or right as prompted by the Observer; then it turns the chair left or right until released; and finally moves the chair forward again. This sort of switch use has parallels with single switch row-column scanning in terms of the changes in switch function and subsequent cognitive demands upon the user, but is considerably more demanding than the original 'automatic' bump and turn. Such a 'user-controlled' set of bump tools has yet to be tested in the schools.

The bumper design is still evolving, in part to make the system more robust, and in part to incorporate the ultrasonic sensors which form the basis of the collision avoidance system.

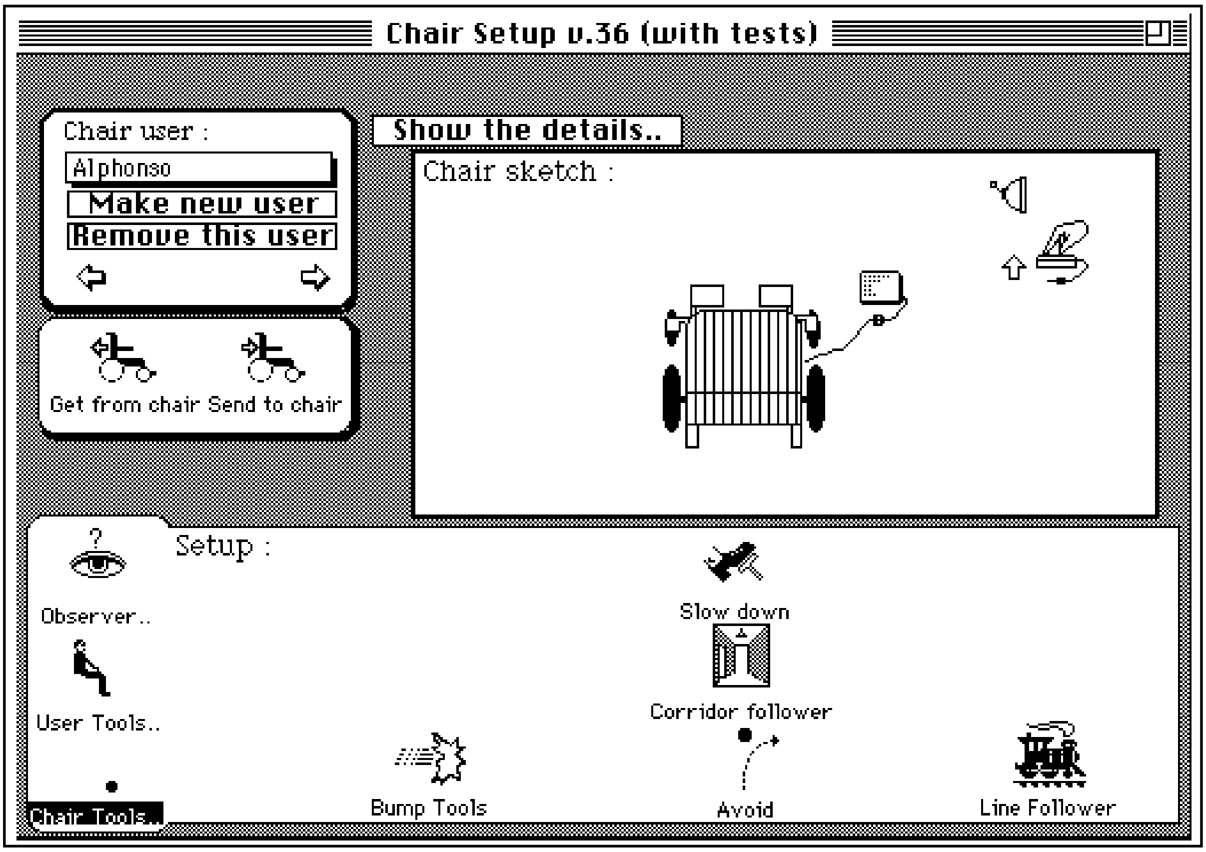
Enclosures

A major design issue during the project revolved around how many units were needed to house the electronics, the tradeoff being between modular costs; communication and wiring costs; user convenience and ease of understanding the system; and ease of access. For example, during the project the speech synthesiser has migrated from being a standalone item to being incorporated in another unit, reducing the wiring 'rats nest' considerably.

User Setup Tools

The Smart Wheelchair is highly tailorable: it follows that much effort went into devising user setup tools which are easy to understand and handle. At present, there are four ways of tailoring the chair to different user's needs. The least useful, from a teacher's or therapist's perspective, is via the polyForth system. More accessible (but more limited in scope) is the hardware ToolBox.

An alternative technique is to pass control codes to the chair via the RS-232 serial line. However, these are somewhat arcane and give little support to the teacher in visualising the current configuration, or in storing and recalling complete setups found particularly useful. (This latter requirement is most important when a chair has multiple users, and reconfiguration take place often). To meet these needs, the evaluation team developed the Macintosh based package shown below: with it, teachers can see at a glance the current configuration, can store sets of different configurations, and can exchange the setups by pointing at icons rather than through text interactions.



Computer-based setup tool

Switches and Controls

Control design or specification was probably the most intensive area of evaluation feedback. Wherever possible, existing controls already used by a child (for accessing computers, communication aid or activating toys) were utilised to drive the chair. However, in some cases special switches, adapted joysticks or computer-based communication and control systems had to be designed and built. These included -

Finger Switch

This switch was designed to allow someone who has good control over flexion and extension of a finger to operate the chair. The switch is based on a hall-effect sensor which detects the presence of a field produced by a small magnet. Both magnet and sensor are mounted on a cotton glove. The switch has the advantage of not being a targeting device: the user does not have to look at it during operation. Where a rider's proprioceptive abilities are poor or not well developed; or where multiple demands are being made on visual attention (as in the case of driving whilst operating a scanner); or where fine motor control is possible in one part of a limb which is otherwise poorly controlled, such switches can be very helpful. Accidental activations are reduced, and attention can be focussed elsewhere. Both of these points are desirable in a dynamic environment such as a powered wheelchair.

Analogue Joystick Interface

For one child, the ability to plug a normal wheelchair joystick into the chair was considered desirable, giving the user proportional control. An interface was designed which allowed the joysticks removed from the DCL motor controllers to be plugged into the joystick socket on the SwitchBox. When the joystick is plugged in, the chair automatically recognises that a proportional control is present and configures the software appropriately (and motion tools are disabled).

Wheelchair Scanner

A scanning system was designed that combined both communication and chair control. A number of commercial systems were investigated but none offered all the facilities required. These were:

- the ability to animate the choice prompt displays.
- the availability of voice prompts and voice confirmations (using different voices for each).
- Serial communication with the wheelchair.
- the ability to accept ascii control strings *from* the wheelchair.
- the ability to incorporate digitised pictures as prompts.

The system was therefore programmed in HyperCard for use with a Macintosh PowerBook computer.

For more details of the overall design evolution, see the DRC Technical Report on the Smart Wheelchair.

As a result of the continuous feedback, the Smart Wheelchair is now a stable and robust design. Failures are rare, and usually confined to lifed items such as bumper foam. Using the experiences gained through the twelve school-based chairs, a redesign of the system has taken place (funded by the associated EEC HORIZON project). The redesign enhances the second-stage Smart Wheelchair for use with an adult population, taking into account new technologies and standardisation developments within the rehabilitation industry. The same chassis is currently in use, but many other details have changed.

Future development should concentrate on enhanced tools to help children in their transition to more complex environments beyond school. Part of this will involve improved integration of the Smart Wheelchair with other aids. Specific attention is still needed to enhance collision sensor life.

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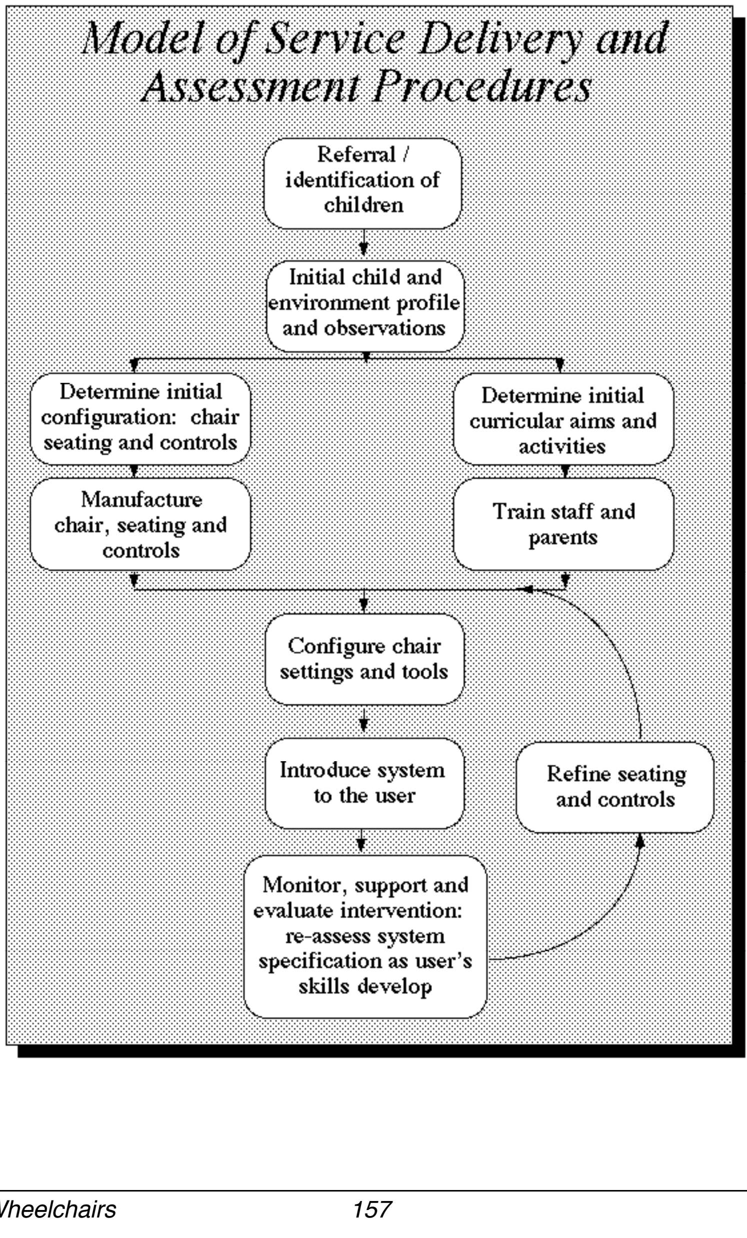
7. Future Planning: Manufacture and Service Costs, and Potential Users

7.1 System and Support Costs, and Provision of Service and Support

In this section, we outline the costs of acquisition and modification of the Smart Wheelchair, giving indications of associated support costs. These figures are derived from the case study wheelchairs, and should be treated with caution. Extrapolation of costs from prototypes and projects to products and services is difficult. The main reasons are uncertainty about how services might be provided, and the best manufacturing route. Because we cannot be accurate about future provision environments, we have adopted the following strategies.

- Firstly, we estimate service costs in terms of professional time, not money.
- Secondly, we note (but do not attempt to quantify) where component costs are changing.
- Finally, we make no attempt to surcharge any of these estimates with the necessary costs of staff training, travel, personal or corporate insurance, standards testing and clearance, or product research and development which will be part of any larger scale commercial or quasi-commercial ventures.

We take service aspects first.



CALL's action research project put in place a simulated service environment in order to refine our understanding of what is involved in delivering and supporting continually extended systems. This environment (consisting of manufacture of basic Smart Wheelchairs, assessment, provision of training, seating and control adaptation services, telephone advice, and maintenance) is integrated into the cyclic model shown on the previous page. The stages involved are:

Initial referral

As with communication aids 'referral' is not merely an administrative preamble to the child being seen by the team. Rather, it is a filtering process: a mixture of discussion about the state of the child and his/her environment, the aims for that child, and the appropriacy of the Smart Wheelchair as a tool to help meet those aims. We have found that time is well spent here, and therefore the referral process often involves preliminary discussions between teachers, parents, and therapists, and both technical and augmentative techniques staff. It is not uncommon for this process to take two or more working days, aggregated across the professional staff of both school and centre.

Assessment: Child profiling and observation

This exercise fleshes out the details provided in the initial contact report and discussions. It will involve a meeting between teaching and therapy staff and the wheelchair key person (up to half a working day), together with initial observation and video sessions, preferably in both home and school (taking the wheelchair team member a further working day). Follow up planning with technical staff takes the form of discussions with technical staff, and the writing of a preliminary profile and strategy. These may take a further working day.

Assessment: Configuration design for seating, controls, tools

With the initial profile to hand, technical staff undertake detailed measurements for seating and controls prior to deciding whether off-the-shelf solutions are possible, or if a system has to be built or extensively modified. Usually two technical staff are involved, and the exercise may take a quarter of a working day each.

Assessment: Curriculum / intervention planning

Once the system is designed, the wheelchair key member then discusses and refines the intervention plan with school staff. This discussion may take one or two hours. Any changes need then to be incorporated into the planning documents.

Manufacture and adaptation of chair, seating, controls

Basic system costs are discussed later. The costs of adaptation can vary greatly. It is rare that seating and control systems can be created with less than a person-week of effort: usually more.

Initial staff/parent training

Initial training sessions will involve at least one school staff member (maybe more if the school is new to the Smart Wheelchair, or if the tailored system is particularly novel, or if a team teaching approach is being adopted), together with parents and one member of the wheelchair team. (In our project sessions, there were more team members, because of the experimental nature of some of the designs. In production, all training could be carried out by one wheelchair team member.) These sessions take around two hours.

Initial chair configuration

Software changes were often needed in the project prototypes: however, such forms of configuration are becoming rarer as the facilities of the Toolbox and its more sophisticated computer-based counterpart expand. The configuration exercise is now taken as part of introduction and training.

Introduction and initial training

For an experienced school team, it is unnecessary to have a wheelchair team member present during initial training. If the school team is not confident, however, then up to three or four introductory sessions might be set up, each with perhaps an hour of contact by teacher and team member.

Monitor and re-evaluate

Refine and reconfigure seating, controls, intervention plans, and tools.

The degree to which a school might want to call on the wheelchair team to help in re-assessment and reconfiguration will depend on the school team's experience, the extent of adaptation of seating or controls needed, and the local resources it can call on. As can be seen from the case studies, sometimes the Smart Chair had to be altered considerably over a short period. However, skill plateaux can be quite extended, and the refinements well within the technical competence of the school staff.

Not shown in the service model or the description of resources needed for it are telephone support and maintenance. The reliability of the Smart Wheelchair is currently quite good, but it would be wrong to estimate the mean time between failure (and therefore the maintenance costs) for any commercial derivative.

The validity of these estimates depends in part on the degree to which actual service provision can be set up to match this model. There are several possible service providers. Until recently, the most obvious places to develop expertise in Smart Wheelchair services would have been Health Authority mobility centres. However, rapid changes in health services means that the role of such centres is now not so clear-cut. The Health Service 'market' favours well established services and systems, but makes specialised services which focus on bespoke system designs hard to establish. Our experience suggests that, in the current climate, health authorities are not going to take up novel problems when they cannot solve their present ones. Fragmentation of policy for provision in the name of market forces means that any innovation seeking to find a widely influential launch point is thus likely to be frustrated.

Independent commercial provision is much in favour as a health and education service solution. The problems here are that there needs to be a coherent market for the hardware systems to be in place before commercial service support can build on it. One technique used by some Communication Aid manufacturers is to bundle initial assessment and training costs with systems. However, a major difference between service and support needed for Smart Wheelchairs and that needed for augmentative communication aids is the degree of adaptation, and the regularity of review and changes. Service bundling has also come under increasing pressure recently from criticism about independence during assessment. Such service provision also needs up front investment by manufacturers, who are wary about individualised products (see below). Finally, the problems of geographical distance are severe, especially when it comes to seating and control adaptation.

A third approach we have considered is more inhomogeneous in nature, but is probably more appropriate in the current climate. It involves identifying, in particular regions, potential collaborative groups of cross-disciplinary specialist centres, and then enlarging their collective role to the provision of smart wheelchair services. The most obvious centres are those already involved in provision of wheelchairs and seating: however, they are not the only candidates to be a regional focus. Given the close relationship between the Smart Wheelchair and other augmentative systems, it makes sense to use augmentative communication centres where possible. Some of the best of these are funded by local education authorities, or are national centres with special local responsibilities.

While it is not clear that government would support centralised services, they may see the advantages in efficiency to be gained by building on existing skills in this way. (In any case, centralised services suffer from well known disadvantages of geographical remoteness and lack of patronage by local authorities and health boards under pressure to find local solutions. The Centre-Satellite model promoted by CALL in the early eighties has taken a decade to come into effect, which is too long a timescale: the innovation would atrophy and die in the meanwhile.) We suggest that a workable strategy would be to identify interested existing service providers, enable them in their new role by supplying them with basic assessment tools and training, and further supporting them through central loan services (much as is currently done for communication aids).

This last strategy also helps alleviate problems typical when new technologies developed by small independent groups are brought to market, namely the severe skills shortages due to lack of apprentices. Working through established centres would enable the service providers to ramp up in a controllable manner, without their other commitments (to manufacturing, standards testing, and development) suffering. However, such a strategy would take time to put into place, and would need constant attention and repair: the price to be paid for lack of national policy is local administrative waste.

We now turn to hardware costs and manufacturing issues, beginning with an outline of the costs associated with tailoring and adaptation of the project chairs. Note that in the following two tables, component costs tended to be small in comparison to labour costs, and most items are therefore estimated on the basis of construction time.

Seating

Our partners in Princess Margaret Rose Hospital Bioengineering Centre assessed and provided seating for each chair user. In some cases complete seats were designed and manufactured from scratch, while in others a frame was built to accept a modified Britax car seat or the child's seat insert from their manual wheelchair. A summary table of seating systems together with an estimation of costs (inclusive of parts and labour) is shown below.

USER	SEATING SYSTEM	EST. COST
Individual	individually designed and manufactured (foam, wood and metal)	£ 1,000.00
Individual	Modified Britax car seat with sub-frame	£ 500.00
Individual	Modified Britax car seat with sub-frame	£ 500.00
Individual	Own manual wheelchair insert, with sub-frame	£ 300.00
* Mobility group	1 small and 1 medium standard Newton seats	£ 300.00
Individual	individually designed and manufactured (foam, wood and metal)	£ 1,000.00
Individual	Own manual wheelchair insert, with sub-frame	£ 300.00
Individual	Own manual wheelchair insert, with sub-frame	£ 300.00
Individual	individually designed and manufactured (foam, wood and metal)	£ 1,000.00
Individual	Modified Britax car seat with sub-frame	£ 500.00
Individual	individually designed and manufactured (foam, wood and metal)	£ 1,000.00
Average		**£ 610.00**

* The mobility group are the three children using a shared Smart Chair to develop driving skills for ordinary powered chairs.

Controls and switching

Some children already had satisfactory switches or controls for accessing computers or augmentative communication systems and so these were adopted as initial switch systems for driving the Smart Chair. Others were assessed by a joint team comprising occupational, speech, and physiotherapist, teacher, parents and the research team and commercially available switches and controls purchased.

However, most of the children were supplied with specially designed control systems by CALL or the Bioengineering Centre. As we described in the case studies, these ranged from a sensor to detect flexion and tension of a fore-finger, regardless of the position of the child's hand in space, to mechanical and electronic modification of a standard wheelchair joystick to provide gated digital output. The table below shows the control systems supplied to each user, with an estimation of the time and component costs required for assessment, design and construction.

These costs are not one-off. Improvement of fine motor and control skills is an aim for almost all the children and so, as skills develop, additional or alternative controls are provided.

USER	INITIAL CONTROLS	ADDITIONAL CONTROLS	EST. COST
Individual	custom finger flexion switch	Custom laptop-based scanner	£ 2,000.00
Individual	modified analogue joystick (Fwd)	lever switch (right steer)	£ 480.00
Individual	custom flush tray switch		£ 450.00
Individual	modified analogue joystick (Fwd)	2 lever switches (left and right steer)	£ 450.00
Mobility group	own/commercial controls		£ 100.00
Individual	lever switch		£ 30.00
Individual	custom squeeze switch		£ 480.00
Individual	custom arm-raise switch	lever switch replaced arm-raise switch	£ 480.00
Individual	modified analogue joystick (Fwd)		£ 480.00
Individual	modified analogue joystick (Fwd)		£ 480.00
Individual	custom switched joystick (Fwd)		£ 390.00
Average			**£ 530.00**

In 1992, the basic chair costs, excluding resources needed in schools to make effective use of the system, looked like this:

Smart Wheelchair supply costings (estimated)

Basic chair (Newton Badger Epic chassis, Control Dynamics motor controller, Smart electronics, sensors, speech sythesiser and labour)	**2825**
Initial assessment (at least 2 person days)	480
Seating:	609
Switches/controls:	348
Chair adaptation (0.5 person days):	320
Staff training (at least 2 person days)	480
Support & maintenance (assume 2 person days)	480
Total support costs	**2717**
Total cost	**5542**

Since then there have been inevitable changes in component costs. Some switches and other controls which we might otherwise have had to hand craft have come onto the market, reducing their cost. The effort needed to build the chair has reduced as a result of engineering redesign, and future highly tailorable communication aid systems such as that being developed by the Comspec project (Lundalv, 1993) will mean cheaper tailoring of more complex integrated communication and mobility systems. Economies of scale are not reflected in the current costings.

On the other hand, basic chassis costs have risen somewhat. The cost of buying a Smart Wheelchair depends on the balance between changes in price and availability of off the shelf or user tailorable systems, and those which need special manufacture, and the degree to which services are bundled with purchase price.

One complicating factor in costing the system is the degree of modularity. It may not be possible to determine what components are needed until assessment has taken place with a trial version of the chair. Changes in specification are also likely later in the cycle of service and provision, and as part of this, some people might want to *downgrade* their system. The project team see three mechanisms to help here. The first is commercial leasing of subsystems for assessment or during the training period for transitional chairs. A second is a loan bank. The last possibility is sale and buy back.

Which of these is workable depends on the eventual service and manufacturing organisation. The CALL Centre has experience of running an extensive loan bank, and see this as a highly efficient aid to assessment services. However, either of the other two would work, albeit at more cost to taxpayers.

Options for manufacture and supply

The following options are open to the team for manufacture of the Smart Wheelchair.

- A commercial manufacturer of wheelchairs or wheelchair controllers could be licensed to manufacture and market the Smart Wheelchair modules as part of their range. The project team have begun discussions with a number of potential commercial firms. However, we are not encouraged by what they say. In a time of recession, manufacturers are resistant to taking new risks which come from outwith their own planning exercises. Moreover, although the market for Smart Wheelchair components is probably not small taken overall, it is highly differentiated, and therefore unattractive to manufacturers who have no real experience in supplying highly tailorable systems.
- A cottage industry could be set up by the development team, following the well established tradition of many other augmentative communication aid teams. We need to be guided here by the large numbers of these enterprises which have failed during the late eighties and early nineties, due partly to the lack of marketing base and the inability to service customers far afield, and partly to the inability to generate enough revenue to support the ramp up process. Put at risk, meanwhile, are the existing responsibilities and career structures of team members, and the further development of the chair.
- A third option is for the team to subcontract production on a small scale initially, and focus their energies on service aspects (which will be controllable if only because supply will be constrained). This strategy will allow the team to establish market credibility, and could work well if combined with the approach outlined above of working to develop targeted regional centres of expertise. This last approach is the team's preferred solution for the interim period. Note, however, that neither economies of scale nor wide availability of the Smart Wheelchair can be delivered by this means.

In summary: service costs for highly tailorable systems outweigh acquisition costs. Although this is accepted by users of other complex systems (such as commercial users of personal computers, who expect to pay ten times the hardware costs of a PC for service and upgrades over its lifetime) it is alien to educational support mechanisms, and difficult in the present climate of any central / local government funding constraints. We therefore believe that Smart Wheelchair provision can only ramp up slowly, and this can best be achieved through extensions to existing regional provision (making good use of non-mobility resources with relevant expertise), backed up by training, assessment packs, and a loan bank.

The manufacturing and service model which can be set up also depends on take up of Smart Wheelchairs. We turn to the potential market next.

7.2 How General is the Need for Augmented Mobility?

Potential users of Smart Wheelchairs

While it was not the intention of this evaluation to carry out a survey of potential users of the Smart Wheelchair, it is clear that some estimation of the degree of uptake is vital for planning chair manufacture and services. There are now clear indicators that the range and number of users could be extensive:

The current wheelchair has proved an effective aid for children who have mobility problems which have proved intractable using conventional powered wheelchairs. Several such children were identified just in the three special schools in the project, and there is every reason to believe that these children by no means exhaust the possible users, even in our sample. Given that the mix of children in our project schools is representative of special schools across the country, it seem reasonable to suppose that at least three or four Smart Wheelchairs could be used in many other special schools for individual users.

Smart Wheelchairs have also proved their worth as transitional training tools, on a shared basis. Some of our case studies had been rejected for conventional powered wheelchairs before using the Smart Wheelchair. We are convinced that a pool of similar border-line, but rejected children exists, and that they could be identified and retrained using Smart Wheelchair techniques. The implication for production is that there is also a market for institutionally owned chairs.

The Smart Wheelchair team is just now beginning to work with adult users of the Smart Wheelchair. That exercise has identified new opportunities for using the relatively unexplored potential of the Smart Wheelchair to integrate with other technological systems (such as workstations, smart environmental controls, and new communication systems) to open up education, training and work opportunities both for adults with stable disabilities, and for those suffering from degenerative complaints. The adult market, perhaps boosted by elderly users, will increase the overall demand for chairs and services to the benefit of younger users.

We have not explored the use of augmentative mobility with some significant groups of disabled or handicapped children, who nonetheless appear as though they could benefit. Among these are children with complex combinations of physical and visual difficulties, for whom exploration is doubly problematic; and children with severe and profound learning difficulties (for whom the original Hull Unibuggy was designed - not to improve mobility, but to shape understanding of cause and effect). We have also not explored the Turtle - like qualities of the Smart Wheelchair in more advanced educational curricular activities. Blind, multiply handicapped children, like many of those in our current study, would be candidates for personal Smart Wheelchairs. In contrast, the other two areas could be served by institutionally owned systems used as part of specific educational programmes.

Most mobility surveys are based on traditional understanding of what powered mobility systems can do and how they are used. As a consequence, they fail to expose much larger potential markets. We should like to see a fuller survey of the market, including the groups above.

The project team have been carrying out some ad-hoc market testing exercises, based on the dissemination activities. They have encouraged professionals who have attended training sessions (and who are therefore in a reasonable position to judge the usefulness of the chair for their own clients) to register provisional referrals (called ‘statements of interest’) in anticipation of assessment services and wheelchairs coming on stream. As an indication of the potential number of users, after one of the one day seminars (held for Scottish teachers and therapists, and presented by a mix of the CALL team, the Schools teams, and parents), the Centre received just under fifty statements of interest. Some features of the responses are summarised below.

Statements of Interest by Region	
Grampian	26
Lothian	7
Dumfries & Galloway	7
Fife	5
Central	4
Total	**49**

(Grampian region provided more than 50% of the seminar attendees.)

The responses were disproportionately biased: heavier returns came from people who knew the CALL Centre and its work well, or who were themselves involved in augmentative techniques.

All three schools currently using Smart Chairs identified children who might benefit **in addition** to those children currently using Smart Chairs: 4 children from Westerlea; 2 from Graysmill; and 1 from Oaklands.

Statements of Interest by Discipline	
Physiotherapists	26
Teachers	20
Occupational Therapists	2
Speech and Language therapists	1
Total	**49**

The spread of professionals returning questionnaires reflects the current responsibility for mobility although it is encouraging that the second largest group is teaching staff. It is perhaps surprising that Speech Therapist referrals are so few given that the majority of Smart Wheelchairs in the CALL project have been used by either classroom auxiliaries or speech therapists, and given that over half the clients were described as having a speech and language problem (see 'Main client disabilities').

Age of Clients	
Under 5	7
5 - 19	34
19+	8
Total	**49**

The seminar placed emphasis on mobility as an education activity.

Main client disabilities	
Severe Physical disability	45
Speech/language problem	25
Visual impairment	4
Learning difficulties	3
Specific learning difficulty	4
Total	**81**

Most children have more than one problem and the medical condition is most often some degree of cerebral palsy.

Intended use for Smart Chair	
Motivation	43
General education/classroom use	37
Speech, language & communication therapy	29
Physiotherapy	29
Mobility	27
Training for powered mobility	18
Occupational therapy	17

The balance of proposed uses for the Smart Chairs indicates the problems which face staff in schools when trying to create motivating activities for children. One slight surprise was the relatively small percentage who saw the chair as a means of mobility training.

Intended location for Smart Chair	
Home	41
School	39
Day Centre	8
Hospital/residential home	8

This particular seminar focussed on children of either school or pre-school age and the statements of interest were skewed in this direction: thus the intended location of use was mainly home and school. We would expect a different result if we presented seminars on the current work for adults.

Smart Chair features expected	
Bumpers/bump detectors	45
Individualised switches	40
Individualised seating	39
Rangefinders	35
Switch interface	25
Motion tools	24
Integrated mobility/communication/computer acces	17
Scanning interface	13
Adapted joystick	13
Line following	8
Other (full assessment)	1

The information on likely Smart Wheelchair features required should be viewed with caution since it is unlikely that staff returning the questionnaires can make precise forecasts on the basis of one day's Seminar. It is evident that there are some areas of misunderstanding: for example, 40 out of the 49 require individualised switches but only 25 seem to want the switch interface needed to connect the switches to the wheelchair. (With hindsight our meaning was unclear in the questionnaire: we wished to separate out those children who already had switches and therefore just required switch access using an interface, from those who require switch assessment and customised switches as well). Otherwise likely features are much as might be expected: most children require switch access, seating, and sensors to avoid damaging themselves or their environment.

7.3 Effectiveness and appropriateness of formative evaluation in the development of new technological systems

We designed our evaluation around formative intervention, planning that the evaluation team would be involved in production and testing of materials, and in day to day support of the teachers and therapists in the collaborating schools. Our proposal made this clear:

> *"As with many other powerful new technological tools, the very breadth of opportunity is itself a development problem. It is not sufficient to offer such technical tools to teachers and therapists merely with vague encouragements to be inventive with them. The last decade's experience with framework (or 'content-free') programs shows the need for well-developed exemplars which can at worst allow teachers not able to do developments of their own nonetheless to emulate good practices of others, and at best act as a spring board for new developments which can feed back into the broader community of users. In our case, the opportunities outlined above form a framework for a series of curricular and training experiments which must, to be useful, lead to the development not only of an understanding of the practicalities of using the chair in classroom and other settings, but should form the basis of tangible dissemination products."*

We therefore favoured the evaluators working in collaboration with the rest of the team.
Was this approach successful?

Formative evaluation can certainly be efficient. This is in part because the evaluator can have several roles (not possible with non-participant observers), and in part because her closeness to day-to-day problems and her adoption of joint responsibility with school staff for some of the outcomes makes communication easier. Given that there was just one researcher with managerial support, it would have been very difficult to have got through the extensive programme of initial choice of children, assessment, profiling, training, adaptation and chair introduction, curriculum support, extended observation and recording, and analysis for the numbers of children and schools involved, without the flexibility which the formative model offers.

We are also content with the product outcomes.

On the other hand, such flexibility brings its own problems. Of these, the most difficult to deal with are undue dependence; timetabling problems; and biased observation.

Undue dependence is a persistent issue. The boundary of responsibility for interventions can become blurred if it is either not properly negotiated in the first place, or becomes unclear as trained participants migrate from the programme.

Timetabling is beyond the control of the research team. Even where schools are committed to the project, their statutory responsibilities come before the needs of external researchers, and delays and slippages are inevitable and unpredictable.

Biased observation can be offset to some extent by techniques such as triangulation, the use of low-inference observation tools, and openness to comment and criticism. However, no-one would claim that the results from this kind of study should be treated in the same way as controlled clinical trials.

As to other aspects: we were disappointed not to have been able to get further with the development of curricular development; and we would have liked more time to deal with the volume of data, particularly from the post-study collection. Both suffered because of our underestimation of how long the process of assessment, initial provision, and training would take, and of the effects of staff changes in the schools. Fortunately, the curricular issues can be pursued under the Nuffield funded 5 to 14 Curriculum Project, now underway.

In summary: we commend formative action research to others introducing new technology: our best advice is to point out its efficiencies to funding agencies doubtful of its scientific rigour. One side-effect should be also pointed out: as a result of this project, three schools have expertise in the use of augmentative mobility, and have incorporated it into their ways of working: and several children are now mobile and socially active who were not before.

8. Conclusions

The Smart Wheelchair has proved itself a powerful tool in motivating and enabling children with poor mobility who might not otherwise manage a conventional powered chair. For such children, it is at its most effective when used as part of an integrated curriculum, itself tailored to the needs of the child. As with other new technologies, putting such a curriculum in place is difficult.

The factors which will allow Smart Wheelchairs to be used effectively in the future are:

- Chair availability
- Service support (including training)
- Curricular support

The project team came to the following specific conclusions:

Safety
The Smart Wheelchair is a safe learning environment for physically, cognitively and perceptually impaired children. Those in our study were generally unafraid of the system, even in the early stages. The most nervous child was the youngest, and he overcame his fear after careful introductory sessions. The Smart Wheelchair is also safe to use, and its self-monitoring systems work well. New tools will improve safety further. We have recorded no regression in children's condition which could be attributed to chair work, or noted over-dependency on the chair. On the contrary, it encourages improvements in the areas outlined below.

Motivation
Smart Wheelchairs and the mobility they promote, can be effective motivators in situations where other stimuli have failed. Children on the project put great effort into operating the chair controls, sometimes over extended periods. Improvements have been recorded in children of all ages, with various conditions affecting their mobility. Even children who have had the disappointment of not being able to control conventional powered wheelchairs have persisted in this new environment.

Developmental improvements
This motivation can be exploited to develop mobility itself, assertiveness, exploratory behaviour, and persistence. Initiation improves in both interpersonal, and person-to-chair interactions. Secondary benefits of these improvements include the opening up of better functional environments for communication and learning. The real-world benefits of improved mobility are encouraging better social interaction and, with it, better communication. Children have also shown improvements in physical tone and control.

Transferability of skills
The skills needed to operate a Smart Wheelchair have proved to be transferable to other situations. Specific skills associated with control, attention, and scanning in the Smart Wheelchair are close enough analogues to those in other augmentative systems for them to be useful bases for development. To make best use of these opportunities, staff need to be aware of potential targets for transfer, and be ready to set up curricular and communication opportunities in which these will be needed. This argues for careful integration of augmented mobility experiences into the day to day activities of the child.

Training for conventional powered chairs
Smart Wheelchairs can also be used as effective transitional training aids en-route to conventional powered wheelchairs, for those children for whom the initial step to analogue control is too great, or where there is doubt about other driving-related abilities such as concentration, vision, or the ability to estimate and plan. It is not always easy to determine if a child will succeed in this task: where learning is slow, the child should be treated in the interim as a potential long-term user of a Smart Chair, with all that implies for long term use. We have doubts about the effectiveness of short-period training sessions without the ability to practice at leisure and in functional settings.

Most effective environments
Complex system technologies like the Smart Wheelchair show most benefit when they are used as integral parts of a broad curricular design. Occasional use is as unrewarding in the curriculum as it is for general mobility. Sharing chairs leads to counterproductive timetabling problems, and lack of perceived worth by the rider of a non-owned resource.

Time-on-task
More variability in the responses of the children on the program can be attributed to lack of opportunity to practice due to non-integration with other activities than to individual differences in abilities. The most effective environment appears to be when the child has a mix of structured tasks, and extended unstructured opportunities to practice trough exploration and play. Care is needed when staff changes are made to ensure that the aims and ongoing programme are maintained. Novel tools and techniques are at particular risk to disruption due to support team changes.

System design
The Smart Wheelchair itself is flexible and robust. Future development should concentrate on enhanced tools for transition in more complex environments beyond school, and into improved integration with other aids. Specific attention is needed to enhance collision sensor life.

Supply, support and service
There is a market for Smart Wheelchairs, but it is complex. To be effective, supply, training, assessment, seat and control tailoring, and long term support must all reflect the unique nature of each chair and user, and the developmental stage they have reached. Over the product life, support costs will be far greater than hardware costs. Such a situation is common in other tailorable systems (such as commercial computer systems), but rarely understood in the context of mobility systems, and difficult to put into place under current Health Service and Educational provision. A possible strategy for service provision would be to build on and extend the expertise of existing regional centres, including augmentative communication centres, supporting this extension through initial training, assessment packs and loans.

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