Paraplegic Trainees and Operators in Engineering/Technology Environments.

E.P. O'Herlihy, W.F. Gaughran

Department of Manufacturing and Operations Engineering,
University of Limerick.

Abstract

Research indicates that there is very little integration in training and operations in engineering manufacture and processing, of a highly valuable human resource – wheelchair users. As the general population are shifting in age balance and most are living longer the proportion of people who are wheelchair users will increase. Consequently the need to meaningfully include people with physical disabilities in the workforce will increase dramatically. Both economically and socially paraplegics are a valuable asset and have much to offer in engineering environments, which will benefit all. By integrating paraplegics in the engineering environment, areas such as safety, ergonomics, access, workspace design and layout will enhance training and working conditions for all.

The problems identified for solution, by the ongoing research at the University of Limerick, in endeavouring to integrate the paraplegic user in engineering environments are both practical and attitudinal. This paper will discuss four key areas relating to educational and operational inclusivity of paraplegic wheelchair users into engineering workshop and classroom environments. These are safety, access, bench design/work-area design and stand-drill design. The research shows that, by addressing and combining these elements a range of previously unavailable activities may be undertaken by wheelchair users in a safe and productive environment.
Key words/phrases: *Paraplegic ergonomics, safety, inclusive design.*

Introduction

If trends and proportions internationally of wheelchair users in engineering environments are similar to that in Ireland then there is a major task to be undertaken to integrate wheelchair users. The integration of the wheelchair user into the Irish education system is currently inadequate. At present there is little evidence of wheelchair users being involved in engineering/technology environments. Research carried out on 121 post primary schools in Ireland indicated that only thirty-eight students who use wheelchairs were studying, out of student population of 54,793. Of the thirty-eight only four were involved in engineering/ technology subjects.

Similarly in third level education the number of students with physical disabilities is also small (0.12%). In 1998/1999 a mere 0.0049% of the undergraduate population were students with physical disabilities, studying engineering[1]. A survey of 120 industrial workshops indicated that there are no wheelchair users working in engineering environments in Ireland and only 0.91% of the engineering workforce represented employees with disabilities. It is not only in the manufacturing and engineering industries that the wheelchair user is being neglected, as 87% of the members of the Irish Wheelchair Association are currently unemployed.

The integration of the paraplegic user into Engineering/ Technology Environments is presently largely ignored. Research at the University of Limerick endeavours to highlight the safety modifications and key areas that are paramount to making these environments inclusive for the benefit of both the able-bodied and the paraplegic user. There are a number of reasons why the wheelchair user is currently excluded from these environments. These include parental fears for students, student's fear of inadequacy, promotion of the subject and the fact that managers, trainers and teachers feel that the environment is unsuitable for the wheelchair user. Extra effort in the area of the integration of the paraplegic user into the engineering environment is both timely and necessary. With new and current legislation in Ireland, the need to integrate people with disabilities in engineering environments will grow. The Equal Status Act 2000 makes it illegal in Ireland to discriminate on the grounds of disability. The legislation states that an educational establishment will discriminate against a student with a disability, if they fail to do all that is reasonable to accommodate that student. Therefore if a student using a wheelchair wishes to study an engineering/technology subject he/she is quite entitled to do so. Internationally an ageing population will also give rise to the need to employ people with disabilities, as with increasing age the proportion of people with disabilities will increase, leading to a necessity to include wheelchair users in the workforce.

While inclusion of the paraplegic user into the engineering environment is the main goal of this research, the design process has to consider and promote independence for the user, create a normal working environment as well as allow the paraplegic user integrate and bond with other students. It is imperative that the design process should not isolate, segregate or brand the wheelchair user as different to others.

Safety

In an engineering environment safety should be given precedence over other matters and personal safety is naturally a major concern for the paraplegic student. While existing safety requirements in engineering environments may be adequate for able-bodied users, modifications need to be implemented for paraplegic users that will benefit all.

At present there are small numbers of paraplegic users working or training in engineering/ technology environments, and the indications are that they feel very unsafe and uncomfortable. Teachers of paraplegic students feel that the paraplegic user is in danger and that there is a serious risk of injury. Teachers also note that students using wheelchairs need extra classroom attention and this may be perceived as leading to the neglect of other students.

To increase safety for the paraplegic user, current safety issues such as objects falling onto the paraplegic users legs, students working with face in direct line of work as a result of their height and students being a safety hazard in certain situations needs to be urgently addressed. Research shows that the following safety recommendations would be helpful to paraplegic students:

- A specially designed work tray to cover the legs of the paraplegic user.
- Design of a personal protective workshop coat suitable for use by the paraplegic user.
- Supplying all users able-bodied and paraplegic alike with a full-faced safety shield to protect them when operating dangerous machines will provide a safer working environment for all operators.

The indications are that by addressing room safety and safety of operations for the paraplegic user, safety for all will increase. Operation of emergency equipment will be made easier for all students with the addition of easily located lightweight portable fire extinguishers. Accessible emergency stops will allow access for the paraplegic user as well as students of smaller stature. Increasing access to emergency exits will allow easier egress for all. Providing a wheelchair accessible area outside these emergency exits will make egress of the building more efficient. By introducing clear circulation routes, access will increase and the risk of injury and the likelihood of accidents will be reduced. The changes, which result from the above show that paraplegic ergonomic design, will reduce the risk of injury to all users. By promoting this type of design, areas of safety that are currently being ignored will come to the forefront of design to increase safety for everyone.

Access

Designing an accessible safe working environment for the paraplegic user involves a number of design criteria. The following points look at paraplegic ergonomics and indicate the complexity of designing to increase inclusivity.

- Reach zones for paraplegic users are between 400-1300mm[2]. This is vital for storage of accessible tools, work material and equipment on shelves. The optimum height for controls is 1050mm[3] and this is required for locating emergency switches, controls, and tools on the wall. Reach ranges over counters, machines, and benches also need to be considered. Forward reach ranges vary. The forward reach range, over a table, for a 10-year-old boy is 440mm. For an adult the reach range, over a high table, is 545mm[4]. As a result careful consideration has to be taken into account when locating tools on benches, controls on machines and objects/material that needs to be accessed.

- Lateral clearance is of the utmost importance to the paraplegic user and is vital in the design process. Sufficient lateral clearance will allow students to work close to machines thus reducing stretching and risk of injury. It also allows access underneath benches, worktops and counters to increase access and use of equipment. The minimum knee clearance for the adult wheelchair user is 685mm high, 760mm wide and 485mm deep while children under twelve require 610mm high 760mm wide and 485mm deep[5].

- Clear floor space is necessary to allow the paraplegic user access benches, counters, machines, sinks, storage facilities, teacher's desk, emergency equipment, computers and other facilities within the room. For the paraplegic user a clear floor space of 1220 long by 760mm wide is required for forward approach and the opposite for side approach. This applies to both adults and children.

- To allow students enter and exit a room, doors should be designed to allow operation by the paraplegic user. Wider door design will increase access for all. The minimum width of internal doors is 750mm[6] but recommended door widths of 850mm are preferred. Emergency exits should incorporate a double door to increase evacuation rate and to allow other students pass by while a paraplegic user is vacating the building.

- Access aisles and turning spaces are important to allow students circulate freely within the workshop. Access aisles between work areas and other classroom elements should measure at least 1120mm wide[7]. With reference to turning space, a circular space of 1500mm is recommended to allow a student who uses a wheelchair turn 180 degrees [5].

Other areas that need careful consideration in the design process to make engineering/ technology environments accessible to the paraplegic user are portable storage, computers, safety equipment and an accessible sink. Portable storage can result in tools and work material being located centrally and easily for the paraplegic user. It will also reduce the amount of movement for the user and therefore increase productivity. Washing facilities are important in a workshop environment and as a result at least one sink has to be accessible to the paraplegic user. First aid stations, emergency stops and other emergency equipment should be accessible to all. Advances in technology have given rise to the integration of computers into all subject areas and to allow the paraplegic user advance in his/her study an accessible computer workstation is required in all classrooms where computers are present.

Workbench Design

Design of workbenches in workshops of post primary schools needs to be urgently changed, as the current workbench design is ignoring ergonomics for the user and especially so, for the wheelchair user (fig 1). Incorrect working heights, layout design and location of storage have meant that current workbench designs present dangers to all operators. Students spend the majority of their classroom time at the workbench. Therefore it is vital to have this bench designed to allow the user work correctly and comfortably. Current design of workbenches has neglected the integration of the paraplegic user and by incorporating paraplegic ergonomics into the design the workbench will become more user friendly to all. Students stature is one example of a problem in current workbench design, as the height difference between a fourteen year old student and an eighteen year old student could vary as much as 500mm yet they both use the same standard workbench. Resulting from this research the proposed workbench design will cater for different varied heights by incorporating adjustable height.

Design of a workbench needs to consider a number of key factors such as work posture, reach, ergonomics, universal design criteria, anthropometrics, frequency of use, location of tools and aesthetics. According to Das and Sengupta [8] an industrial workstation design objective is to ensure that the majority of the population of the intended user group can be accommodated comfortably, without any harmful posture. For physical design of industrial workstations, the four essential design dimensions are (1) work height, (2) normal and maximum reaches, (3) lateral clearance and (4) angle of vision and eye height. For engineering/ technology environments the major concern for workbench design and the inclusion of able bodied and the paraplegic user are one to three above.

Figure 1. A wheelchair user at an inaccessible workbench

Incorrect working heights will cause a number of problems. When standing low work surfaces result in lower back pain, as work is done with forward bending of the body. For sedentary operators, working height which is too low results in both back and shoulder discomfort. For standing and seated positions, a high work surface will cause stiff and painful neck and shoulders, as arms must be held high. Correct working heights for wheelchair users are critical, as the most common physical complaint from wheelchair users is back pain. It is critical that the paraplegic user can work in a neutral body position. The more the sitting workstation differs from ensuring neutral body positions, the greater are the stresses on the musculoskeletal system[9].

Correct working heights are currently being ignored in most workshops in post primary schools. Students carry out a vast array of tasks on the workbench, ranging from light to heavy operations, yet only one working height is available on the bench. There was little evidence of foot stands in place to allow the operator vary their working height. An adjustable height workbench is the simplest solution to cater for all students, which will include the paraplegic user. Additional features to make a workbench accessible to the paraplegic user need to be considered.

- The provision of lateral clearance is critical for the able-bodied user but even more so for the paraplegic user to allow close proximity to the work area.
- The workbench should be located in an accessible part of the room and provide sufficient clear floor space to allow the user work safely and comfortably.
- Tools should be placed on the work surface to avoid over stretching and awkward postures (caused by having tools in lockers).
- Normal and maximum reach ranges of students need to be considered when locating tools and equipment on the workbench.
- The vice needs to be accessible. The wheelchair user prefers to work with the vice close to his/her body, which necessitates having the vice located over his/her thighs and between the wheelchair armrests. Therefore careful consideration in locating the vice on the workbench needs to take place.
- To allow wheelchair access underneath a bench a minimum clear space of 900mm wide is required.

- The worktop surface area also needs to consider the depth of the workbench.

By modifying and changing the current workbench design students can work in a safe and comfortable environment in an efficient and productive manner.

Drill Design

Having made recommendations on safety, access and workbench design in engineering environments the research attention now moves to the drill, generally the most used machine in a workshop. The pillar drill can normally be used for a range of materials, simply by changing the drill bit and the speed of the machine[10]. The drill is necessary for all students to complete any basic project. Therefore it is essential that it be the first machine modified and altered to allow safe operation for the paraplegic user and others. Current machine interface design neglects the principle of designing for all. Redesign of the drill will make it safer, easier to use, increase productivity and allow for the inclusion of the paraplegic user. Current working heights, legislation, design factors and safety need to be addressed to develop a user-friendly machine for all.

From analysing current working heights, the problems faced by the paraplegic user have become evident. Figure 2 indicates the current table height of the average drill in proportion with a student, who is a wheelchair user. From the figure, one can see that flying debris could cause serious facial injuries to the operator. The working height of the operator's elbows and shoulders will be raised while working on the worktable. This can cause unnecessary strain and fatigue resulting in injury to the operator. The position of the vice on the table will make it very difficult for safe operation. Lining up the work piece with the drill

Figure 2. Drill table heights and machine controls are important

bit will also be difficult. Constant bending of the back could lead to unnecessary injury or pain. The controls on the machine are also inaccessible due to the height of the table.

Increasing safety for the paraplegic user on the drill will increase safety for all. Accordingly a number of areas need to be addressed to benefit all. These include training, personal protective equipment, the work area and worktable. All students are required to wear safety glasses while working on the drill. As the paraplegic user is working at a lower level than other students, a full-face shield would better provide facial protection. Objects falling from machines or workbenches could cause serious injury to the wheelchair user, but this could be prevented by making it mandatory that all work-holding devices are clamped to the worktable. This will allow students to operate the machine with both hands in a safe and productive way. With the addition of a tray, maximum protection of the paraplegic users legs is now provided to reduce injury. Correct training should be provided to all students and this should include topics such as general safety, correct starting and stopping procedures, working speed, work-holding best practice and safe operation. The "three golden rules" of drill safety should be outlined to all operators and clear instruction should be displayed. These rules are: always wear safety goggles or a safety shield; always use a work holding device to hold the work piece and always let the machine stop completely before operating it.

Conclusion

Without designing with all the above elements in mind the paraplegic user will be excluded from participating in engineering/technology environments. Designing for all requires the adaptation and modification of current design best practices to encompass a broad range of user capabilities[11]. Designing for all will increase safety for all. The integration of the paraplegic user will have positive implications for all involved in the engineering/technology environments, as it will increase safety and provide a better working environment for all.

Increasing safety and awareness will bring about attitudinal change in teachers, trainers and students. The promotion of the subject area will increase the number of students/workers who use wheelchairs participating in this field. As a result inclusivity in the workplace will increase and the stigma attached to being a wheelchair user working in an engineering environment will diminish.

The design process has to account for the paraplegic users attitudes and right to independence. Positive design has to integrate the wheelchair user without making him/her feel different to others and allow students to work in a normal working environment. No student wants to be classed as different to his/her peers and wherever possible students who use wheelchairs should be fully integrated. The design should not at any stage stigmatise the wheelchair user as different or isolate the wheelchair user from other students/employees. Increased awareness of safety, integration, independence and inclusive design should be addressed and taught to all students, teachers and trainers.

Safety, access, bench design and drill design are critical elements in any workshop environment. Research would suggest that by addressing and combining these elements, a range of previously unavailable activities might be undertaken by the paraplegic user in a safe and productive environment. This paper has discussed ways to integrate the paraplegic user, while increasing safety for the able bodied user. All the areas above need further development, while areas such as tool design and machine design need future investigation to increase ergonomics and ease of use for all operators. New bench design is part of the ongoing research. Currently this design is being prototyped and tested. Further research hopes to develop the areas discussed above and make the integration of the paraplegic user into engineering/technology environments safer and easier as well as contributing to their autonomy.

References

1. Hoey, P. (2000). Students with Disabilities in Higher Education. Initial Findings of the Survey on Provision for Students with Disabilities in Higher Education for the Academic Year 1998/99. Higher Education Authority, Dublin.
2. National Rehabilitation Board. (1998) *Buildings for Everyone: Access and Use for All the Citizens*. National Rehabilitation Board, Dublin.
3. Goldsmith, S. (1984) *Designing for the Disabled*, 3rd Edition Fully Revised. RIBA Publications, London.
4. Goldsmith, S. (2000) *Universal Design*. Architectural Press, Oxford.
5. US Department of Justice. (1991) Americans with Disabilities Act: Accessibility Guidelines for Buildings and Facilities. Federal Register, Washington DC.
6. Building Regulations Technical Guidance Documents. (1997) Access for disabled People, Part M, Department of the Environment, Stationary Office, Dublin.
7. Bar, L. and Galluzzo, J. (1999) The Accessible School: Universal Design for Educational Settings. MIG Communications, Berkley.
8. Das, B. and Sengupta, A. (1996) Industrial Workstation Design: A Systematic Ergonomics Approach. Applied Ergonomics 27(3), 157-163.
9. Abdel-Moty, E. and Khalil, T. M. (1991) Computer-aided Design and Analysis of the Sitting Workplace for the Disabled. International Disability Studies, 13(4), 121-124.
10. Architects and Building Department for Education and Employment. (1996) *Design and Technology Accommodation in Secondary Schools: A Design Guide*. The Stationery Office, London.
11. Clarkson, P.J. and Keates, S. (1998) Design for All: Designing for the motion-impaired user. Cambridge University Eng. Dept. Technical Report, CUED/C-EDC/TR67.

EOIN O'HERLIHY

Eoin O'Herlihy is a Teaching Assistant and Postgraduate researcher in the Manufacturing and Operations Engineering Department at the University of Limerick, Ireland. He Graduated with a 1st Honours in Materials Technology and Engineering (Education), in 2000 and is currently researching in the area of Inclusive Design with reference to paraplegic access to engineering and technology classrooms and machine interface design.

WILLIAM GAUGHRAN

William Gaughran is a Course Director in Technology Education and Lecturer in Engineering Design at the University of Limerick. He is Research Project Manager for inclusive design for facilities and tooling. He is a consultant and researcher to the National Council for Curriculum and Assessment (Ireland) and is the Author of several textbooks in technology education. His research interests include human factors and design strategies and Universal Design.