How to implement inclusive design into distinctive feature hand tool? a design study on fine operation-aid screwdriver

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ABSTRACT

Hand tool design should integrate the concept of Inclusive Design to be accessible to most users. However, current Inclusive Design strategies of product development are mostly used in post-design evaluation. The retention of inclusive properties in product when new functions are incorporated is essential. Fine operation-aid screwdrivers are designed according to user requirements to address frequently-encountered problems when using screwdrivers namely-insufficient lighting and difficulty in properly installing screws respectively. TRIZ method is applied, comprised the improving parameters solving the problems and worsening parameters which prevents the original inclusive design factors from being damaged into the contradiction matrix, and obtains a set of innovation principles. Eight experts were consulted for their design ideas and developed two fine operation-aid screwdrivers embracing the concept of Inclusive Design. Furthermore, factors regarding the two major operating problems were added to an existing hand tools Inclusive Design Scale. After correlation analysis, the inclusive fine operation-aid screwdriver evaluation scale was established. In addition, two more screwdrivers were selected with the same functions and high reviews on the market as control samples, and 39 users were recruited using a quota sampling strategy to participate in Inclusive Design evaluations. The results revealed that the fine operation-aid screwdrivers evidently solved the two major operating problems in terms of the five dimensions including functionality, comfort, professionality, safety, and usability in the inclusive fine operation-aid screwdriver evaluation scale, thereby affirming the rationality and reliability of our hand tool development approach.

1. Introduction

To provide accessible to most users, hand tools should be designed in accordance with inclusive design (ID) requirements, enabling users to complete tasks comfortably, with little physical effort, and while avoiding harm (Aptel et al., 2002; Marsot and Claudon, 2004). Researchers have even suggested that ergonomic requirements for hand tools can be met to a greater extent if tool users are allowed to participate in the product design process or post-design product evaluation (Gao et al., 2021; Kuijt-Evers et al., 2004). However, hand tool development still involves certain difficulties. After the incorporation of new functions into hand tools to satisfy users’ increasing requirements, existing product scales are no longer suitable for product evaluation or as references. For instance, screwdrivers, a commonly used hand tool, have a relatively mature structure and design factors; nevertheless, several problems occur during their use. The screwdriver bit is likely to be damaged or broken because maintaining the balance during use can be difficult. Moreover, the diverse operating angles or low-light environments involved in the use of screwdrivers increase the difficulty of parts assembly. To resolve these problems and satisfy users’ demands, new functions should be added to screwdrivers.

Comfort during operation is a critical consideration in the product design of general-purpose screwdrivers (Fellows and Freivalds, 1991; Vink, 2004). Operating comfort affects consumers’ purchase intention; discomfort during use reduces users’ operating performance and their satisfaction with the product’s performance. However, the incorporation of new functions often changes the appearance of the original product. Therefore, meeting consumers’ comfort requirements while balancing product structure and function remains a major challenge.

To obtain instant user feedback, an increasing number of companies have allowed users to participate and make adjustments to the product designs during development (Dong et al., 2015). Through research on ID, the University of Cambridge established an approach to include user participation in design (Clarkson and Roger, 2010; Clarkson et al., 2013;
Designers can ensure the products and services they design are accessible to the widest range of users by conducting user trials and exclusion calculations. Furthermore, in such a highly competitive market, this approach establishes a basis for innovation that makes products accessible to more users. This approach also provides users who have diverse demands with more valuable products (Macdonald, 2007). Nevertheless, the current ID process is considered too expensive, complicated, and time-consuming (Joy Goodman-Deane et al., 2010). Nevertheless, the current ID process is considered too expensive, complicated, and time-consuming (Joy Goodman-Deane et al., 2010). Furthermore, in such a highly competitive market, this approach establishes a basis for innovation that makes products accessible to the widest range of users by conducting user trials and exclusion calculations. Moreover, users who have diverse demands with more valuable products (Macdonald, 2007). Nevertheless, the current ID process is considered too expensive, complicated, and time-consuming (Joy Goodman-Deane et al., 2010). Hence, to ensure companies and designers incorporate ID into their products, relevant instruments and methods should also be developed in the construction of ID strategies.

In practicality, ID is implemented in product design to develop products accessible to most users, avoid negative feedback, and reduce development time and cost (Lin & Wu, 2015). Wu et al. (2016) initially clarified the relationship between the appearance factors and principles of ID according to the generally applied ID principles for hand tools and user experience surveys. Wu et al. (2016) further evaluated the importance of product design factors, proposed a ID-incorporated development process for mature products, and provided an impression demonstration of including ID into the front-end research on product development. However, the applicability of said process in developing products with new functions requires further verification.

A total of 106 Taiwanese respondents which have screwdriver using experiences (male = 68, female = 38, average age = 43.3 years old, average using experience = 15.8 years) were randomly investigated. Two major obstacles of using screwdrivers were revealed according to respondents’ using experience: (1) insufficient lighting at pinholes due to the complexity of the operating environment, and (2) locking-up difficulty and the possibility of damaging screw threads caused by alignment challenges when screwing down.

Therefore, to solve the above problems and explore the method of hand tool product innovation based on the inclusive design which is to meet the needs of people with different capabilities, the research purpose mainly focus on the following two aspects:

(1) Exploring the evaluation model to assess how the fine operation-aid screwdrivers satisfy the demands of most users (i.e., compliance with the principle of ID);
(2) Estimating the feasibility of incorporating ID in the fine operation-aid screwdriver, implementing ID in the front end (to produce a reference product and make ID more than just a post-design evaluation instrument), and reducing development time and cost.

2. Research method and procedure

2.1. The development of inclusive design

Inclusive Design (ID) can be dated back to the term “Universal Design” proposed by Ron Mace (Connell et al., 1997). Inclusive design mainly focuses on the user’s physical and cognitive inclusive assessment, which highlights more on Human-Centered Design, respects the diversity of users, aims to reduce the requirements of capacity, and provides flexibility in user control, choice as well as tolerance for user mistakes (Steinfeld and Maisel, 2012). Although ID has become more mature in terms of concept, definition and terminology, it is not easy to implement its principles and achieve the expected benefits in practical design practice (Herriott, 2013; Edward Steinfeld and Smith, 2012). In fact, inclusive design should not only encounter various existing challenges, but also solve numerous new problems (Dong et al., 2004). The diversity and uncertainty of product development process lead to different inclusive design and development modes. Inclusive design assessment scales proposed by Connell et al. (1997) are often reduced to post-evaluation tools due to their over-generalization (Lin & Wu, 2015). When faced with differences in product attributes, the principle of openness cannot adapt to the needs of heterogeneous product development (Kett and Warttack, 2015) For example, Tomberg and Kelle (2018) applied inclusive design tools to evaluate wearable design and constructed an evaluation scale of wearable design from the perspective of human factors. As mentioned above, inclusive design is a design strategy integrating various people and background perspectives (social, cultural or personal characteristics) (Bichard et al., 2007). However, the user-centered design concept is based on the current cognition of users. If there is no clear precedent for products, inclusive design will face difficulties in implementation of design practices, highlighting the limitations of ID methodology in the current development.

2.2. TRIZ application in inclusive design

During the process of product development, engineers will convert market and user requirements into specific design factors and define them according to their Engineering Specification (Pahl and Beitz, 2013). After that, designers will develop innovative ideas according to the defined engineering specifications, but there is no certain rule for the generation of creativity, “how to transform abstract concepts into solid design” has been widely discussed. Therefore, how to clarify the relationship between users’ actual needs and product design elements is the key to product innovation design and development stage. TRIZ is a systematic approach to assist designers in developing concepts, removing psychological inertia in an objective way, expanding knowledge

![Figure 1. The solution process of using TRIZ contradiction matrix.](image-url)
domains, “guiding defining problems” and “providing innovative ideas” (Altshuller, 2002; Ilevbare et al., 2013; Savransky, 2000).

When solving problems with TRIZ, designers need to transform the design factors of the product into TRIZ problems, and then use TRIZ tools such as Contradiction Matrix to obtain the engineering specifications and solving direction of the TRIZ problems. Based on the knowledge and experience of similar problems, designers can break their limitation of personal knowledge, solve the problem in a systematic way to avoid thinking inertia (Fey and Rivin, 2005; Gadd, 2011; Lim et al., 2018; Pokhrel et al., 2015) (Figure 1).

Currently, the studies of applying TRIZ method into product development process mainly use the conflict theory of TRIZ to solve the technical contradictions in the process of product innovation design. For example, Hsieh and Chen (2010) applied TRIZ’s conflict theory to integrate the fixture and connection of friction stir welding. Hu et al. (2011) adopted TRIZ’s design method to improve and design wireless mouse products. It can be seen from the above literature that TRIZ’s technology conflict resolution theory can effectively solve the technological conflicts in the process of product innovation design. In this study, TRIZ innovation principle is adopted to solve these problems. By exploring the problem key points and obtaining the innovation principle through the contradiction matrix, the bottleneck of engineering and technical problems can be correctly examined and the conflict problem of general product design can be solved in the early stage of product design.

Figure 2. Research structure.
Regarding the development of the fine operation-aid screwdrivers, the researchers referenced the ID product development process proposed by Lin and Wu (2015) to: (1) obtain the samples of the fine operation-aid screwdriver, (2) establish the fine operation-aid screwdriver evaluation scale and conduct evaluations, and (3) verify the design (Figure 2).

2.3. Obtaining samples

To use the TRIZ for problem solving, designers must first convert the product to be designed into a TRIZ problem and then use the TRIZ tools. The contradiction matrix, for example, obtains the engineering specifications and design direction of a TRIZ problem, overcomes the limitation of personal cognition on the basis of knowledge and experience of similar problems, and avoids cognitive inertia by solving problems systematically. To address the problems of conventional screwdrivers, the optimizing parameters that increased the lighting and facilitated the alignment into general parameters were converted in the contradiction matrix. Furthermore, the design factors of a previously developed inclusive screwdriver (Wu et al., 2016) were incorporated into the contradiction matrix to serve as the worsening parameters for this innovative design. The optimizing parameters were subjected to innovation evaluation to establish the design principle for the fine operation-aid screwdrivers.

2.3.1. Optimizing parameters for the fine operation-aid screwdrivers

User experience surveys have indicated that users cannot see the pinholes clearly because of the complex operating environment and have difficulty in properly installing the screws. Therefore, the corresponding optimizing parameters were incorporated for the two problems in the TRIZ contradiction matrix.

**Problem 1. Insufficient lighting at pinholes due to the complexity of the operating environment.**

Parameter 18 “Illumination intensity” was applied to improve the insufficient lighting resulting from the operating environment or blocked vision during operation, parameter 20 “Use of energy by stationary object” to reduce the energy waste resulting from insufficient lighting during operation, and parameter 35 “Adaptability or versatility” to ensure the screwdriver can be applied under insufficient lighting.

**Problem 2. Locking-up difficulty and the possibility of damaging screw threads caused by alignment challenges when screwing down.**

Parameters 22 “Loss of energy,” 25 “Loss of time,” and 20 “Use of energy by stationary object” were included to reduce the noncontribution
resulting from the energy and time wasted while users align the screw threads. Parameter 30 “External harm affects the object” was incorporated to mitigate the damage caused when users apply force in an unaligned situation.

Moreover, parameters 9 “Speed,” 33 “Ease of operation,” 39 “Productivity,” and 27 “Reliability” were applied to increase the efficiency and convenience of the screwdriver because these are two user priorities.

2.3.2. Worsening parameters for the fine operation-aid screwdrivers

Hand tools design criteria and ergonomic considerations are crucial factors in the design of hand tools and the basis for developing the fine operation-aid screwdrivers proposed in this study. After inspecting mature screwdrivers on the market, Wu et al. (2016) established an inclusive screwdriver evaluation scale by referencing a new inclusive design evaluation scale (Lin & Wu, 2015) and further categorized the inclusive screwdriver design factors according to quantification theory.
Accordingly, the researchers applied these design factors as the worsening parameters for developing the fine operation-aid screwdrivers.

In addition, this study converted the inclusive screwdriver design factors compiled by Wu et al. (2016) into their corresponding parameters in the TRIZ matrix (Table 2). These parameters served as the worsening parameters that prevented certain parts from being changed when new functions were incorporated. On the basis of hand tools design criteria revealed in the literature, the following possible influential parameters were included in the design: “2. Weight of stationary object” and “16. Duration of action by a stationary object” to reduce the screwdriver weight; “8. Volume of stationary object” and “12. Shape” to form a handle with a suitable diameter and shape; and “2. Weight of stationary object,” “19. Use of energy by stationary object,” “32. Ease of manufacture,” “31. Object-generated harmful factors,” and “36. Device complexity” to reduce the extra weight added because of the new functions.
2.3.3. Fine operation-aid screwdriver samples

After incorporating the corresponding improving parameters and worsening parameters of the two problems in the TRIZ contradiction matrix, this study obtained 40 TRIZ innovation principles. The criteria were used for problem solving and as a guide for developing new functions.

Principles with top four frequency ranking were considered the primary improvements to be made:

The innovation principles of Problem 1 (i.e., insufficient lighting at pinholes due to the complexity of the operating environment) were “1. Segmentation,” “3. Local Quality,” “15. Dynamicity,” and “35. Transformation of properties” (Figure 3). The innovation principles of Problem 2 (i.e., difficulty properly installing screws and the possibility of damaging screw thread because of alignment challenges) were “1. Segmentation,” “10. Prior actions,” “28. Replacement of mechanical system,” and “35. Transformation of properties” (Figure 4).

After preliminarily examining the two problems by using the TRIZ innovation principles, eight experts (three users from relevant industries, three senior designers with at least 5 years of experience, and two common users) were invited to select suitable principles and produce design ideas. Finally, two fine operation-aid screwdriver proposals were presented, and experimental samples were drafted accordingly (Table 3).

In accordance with the basic model of screwdriver handles introduced in the literature (Wu et al., 2016) and the two proposals, two fine operation-aid screwdrivers, Sample_1 and Sample_2, were developed (Figure 5).

A socket and light-emitting diode (LED) lighting were added to Sample_1 on the basis of the basic design factors. The socket was installed at the front end of the screwdriver shank. During usage, the front end of the socket attaches to the working surface, and the screwdriver bit adheres to the socket. This prevents the bit from shifting when additional force is applied during operation and ensures the screws are properly installed.

LED lighting was added to Sample_2. Users can confirm whether the screw is properly installed by using the illuminating cursor. A linear lighting model that forms an illuminating circular cursor on the working surface was subsequently designed. When the screwdriver is incorrectly operated or when the working surface is tilted, the circular cursor becomes oval because of the change in light-emitting angle, prompting the user to adjust the operation angle. The LED lighting not only enables users to operate the tool in the dark but also widened the potential operating environments of the screwdriver.

In addition to the new functions, the two samples were designed according to the aforementioned screwdriver design factors. The greatest difference between the new and previous designs was that a longer shank was used in the novel designs. The experts verified that the new functions could help users determine whether the screw was properly installed. They also discovered that the lighting could only illuminate the working surface clearly and in a wider range from a certain distance. Furthermore, a longer shank is more useful in a narrow operating environment where hands have limited access. This highlights that to resolve the problems in designs, the incorporation of new functions might change the original appearance of a ID.

2.4. Establishment of the fine operation-aid screwdriver evaluation scale

A ID evaluation scale should be able to estimate the characteristic development of the target product (Wu et al., 2016). In this study, the researchers referenced a hand tools ID evaluation scale and developed a fine operation-aid screwdriver evaluation scale.

Moreover, similar or repetitive terms in the hand tools ID glossary that was compiled by this institute (Lin & Wu, 2015) were combined to minimize confusion among participants. To ensure the scale items were comprehensible to participants with diverse backgrounds, the professional
2.5. Operation verification

2.5.1. Participants and samples

User evaluation is typically conducted with only a few samples. To increase the representativeness of the participants in terms of sex, age, and education level, the researchers employed the quota sampling strategy (J. Goodman-Deane et al., 2014). Hence, participants were recruited according to the demographic distribution in Taiwan. In total, 39 participants consented to participate, 23 of whom were male and six of whom were used to operating tools with their left hands. Their age distribution was as follows: 15–24 years (n = 7), 25–34 years (n = 8), 35–44 years (n = 10), 45–54 years (n = 7), and ≥55 years (n = 7). Only one participant had no experience using a screwdriver.

Given that control samples should possess the main design factors of the experimental samples, the researchers searched for products with the same functions and high reviews on the market to serve as the control group. The control samples reflected users’ opinion on the fine operation-aid screwdrivers and other existing products on the market (Figure 6).

2.5.2. Procedure

This study constructed a screw-locking experimental scene to simulate the actual use of the products and also examined the relationship between users, products, and environments. A wooden box was prepared, and the back and top of the box were marked with screw locking points.
Participants completed the screw locking task in a relatively dark environment. Prior to the experiment, the researchers explained the experimental task and purpose, the concept of ID, and the properties and method of use of the fine operation-aid screwdrivers to the participants. To ensure that participants' unfamiliarity with the tools would not influence the experimental results, they practiced the task before the formal experiment.

The experimental task was to use the four screwdrivers to lock the screws on vertical and horizontal surfaces. Participants completed the evaluation scale after they locked the screws with one of the samples, and they rested for 1 min to reduce the workload before they used another sample. The experiment concluded after participants operated all four samples and completed the evaluation scales. The total experiment duration was approximately 25 min.

After the experiment, a simple interview was held with the participants to confirm that they fully understood the experimental purpose and had completed the scales according to their thoughts on the new functions.

3. Results

The fine operation-aid screwdrivers were selected as the target product, and a fine operation-aid screwdriver evaluation scale was designed accordingly. The researchers inspected the versatility and uniqueness of existing ID scales and principles and also analyzed the results of their application to the fine operation-aid screwdrivers. Additionally, the differences between the scale established in this study and existing ones were further examined and their feasibility were estimated by employing design evaluation methods.

3.1. Analysis of the fine operation-aid screwdriver design factors

This study employed the concept of ID in product development from the initial stage and established a development process. Taking new functions as an example, the researchers aimed to provide suggestions for the design of fine operation-aid screwdrivers. The overall evaluation of the ID was assessed using the scale item “Do you think this product meets the concept of ID?” Correlation analysis was used to determine participants' thoughts on the design factors of the fine operation-aid screwdrivers; these opinions could serve as a reference for designers and manufacturers to design other fine operation-aid screwdrivers. The development process could also be applied to other types of products. According to the correlation coefficients, the importance of the fine operation-aid screwdriver design factors was as follows:

1. Illumination: line light source > plane light source > point light source
2. Alignment: reticle alignment > socket alignment > horizontal alignment
3. Non-slip handle design: yes > no
4. Handle material: composite > single
5. Handle shape: complex > average > simple

Figure 8. Inclusive design achievement of design verification.
The researchers compared the aforementioned fine operation-aid screwdriver design factors with the screwdriver ID elements proposed by Wu et al. (2016) and discovered that the greatest difference was that the shank of the screwdrivers developed in this study was adjusted from medium to long. The addition of new functions changed the structure of the product. Maintaining both the functions and operability also changed the design. This highlights that the appearance of a product is likely to change as new features are incorporated to satisfy user demands. The importance of the design elements disclosed by the correlation analysis could serve as a reference for designers and manufacturers to design relevant hand tools.

### 3.2. Evaluation of the fine operation-aid screwdrivers

Items with extreme values on an existing evaluation scale were first excluded. Subsequently, we identified the main dimensions through analysis, removed some of the dimensions, and rearranged the order according to their weighted importance. The new dimensions and their importance were thereby obtained (Ferriech and Muller, 1990). We defined participants with the top 27% highest scale scores and those with the lowest 27% scores (low score group 42; high score group 41) as the extreme group and conducted an independent sample t test. The results indicated that all items reached a significant level (p < 0.05), suggesting that they had enough discriminability. The Cronbach’s α was 0.979, suggesting that the consistency of the full scale was high. Item 35 was removed because its corrected item-to-total correlation value was lower than 0.3, demonstrating a considerably lower consistency with the full scale.

We applied the original data to conduct a Kaiser–Meyer–Olkin (KMO) and Bartlett’s test. The KMO value was 0.947; the value of the Bartlett’s sphericity test was 5308.286; and the degree of freedom was 703. The significance level of 0.000, which indicated that the data were suitable for factor analysis. To assess the construct validity of the dimensions of the evaluation scale, a factor loading of 0.5 (Field, 2013; Tabachnick and Fidell, 2001) was used as the benchmark of convergent validity. To examine the discriminant validity of the scale and verify the construct validity of the fine operation-aid screwdrivers, cases for which the absolute value of the factor loading was higher than 0.5 in two or more dimensions were excluded.

Finally, five main dimensions (P1: Functionality, P2: Comfort, P3: Professionality, P4: Safety, and P5: Usability) and 39 scale times were obtained and were named according to the perspectives they evaluated (Table 4). The cumulative explanatory rate of the scale reached 70.289%. In addition, we employed Cronbach’s α coefficient value as a criterion for assessing the reliability of the full scale and its items, and the result was higher than the benchmark value 0.70 (Nunnally, 1978). We thus inferred that the 39 items had satisfactory reliability and validity. After we excluded the inappropriate items on the basis of the results of the item and factor analysis, the scale obtained high stability and credibility, suggesting that the scale was qualified as a fine operation-aid screwdriver evaluation scale.

### 3.3. Evaluation results

The previously obtained five dimensions were adopted as the evaluation principles of the fine operation-aid screwdriver evaluation scale. This scale was further applied to verify the level of achievements of the developed fine operation-aid screwdrivers. The researchers compiled the participants’ opinions on the screwdrivers from the five dimensions and averaged the scores participants provided for each item. The results disclosed (Figure 8) that the fine operation-aid screwdrivers, Sample_1 and Sample_2, received equally favorable evaluation results in each dimension and received more favorable reviews than the control samples did. The reason for the favorable reviews was the illuminating cursor, a key element to help align the screwdriver and the screw nut, did not affect the original operation. This factor satisfied users’ requirement for sufficient illumination, and the operation was more in line with users’ habits. Moreover, the cost of Sample_2 was lower than that of Sample_1, which satisfied the requirements of manufacturers.

### 3.4. Inclusive design principles

This study incorporated new functions and the concept of ID in product development. Through participants’ assessment, five dimensions and 39 evaluation items were obtained. The five dimensions were not completely independent; they were somewhat related. The main difference between these ID principles and existing ones was that the proposed

| CUD and Mace’s 3B principles | Satoshi Nakagawa | UD principle of needle-nose pliers (Lin & Wu, 2015) | UD principle of screwdriver (Wu et al., 2016) | The inclusive design principles proposed in this study |
|-------------------------------|------------------|---------------------------------|---------------------------------|---------------------------------|
| Equitable Use                 | Anyone can use the product equitably | Achieve user’s functionality needs | Fairness and functionality | Functionality |
| Flexibility in Use           | Enable use through various methods | Psychological, spiritual, and social dimensions | Information Perception and Usability (Product Design Features) | Comfort |
| Simple and Intuitive Use     | Use is simple and easy to understand | Aesthetic and Commercial value | Experience and business value | Professionality |
| Perceptible Information      | Can use multiple sensual organs to understand message | Level of work task achievement | Durability and economy | Safety |
| Tolerance for Error          | Improper use of the product will not cause accidents, and the product can be returned to its original shape | Space and environment for Approach and Use | Operational ease | Usability |
| Low Physical Effort          | Improper use of the product will not cause accidents, and the product can be returned to its original shape | Tolerance | Tolerance |
| Size and Space for Approach and Use | Reduce physical burden on users Tolerance | Ensure convenient size and space for use | Adjustability |
| Better Design                | Supplement 1 Durability and economics | | |
| More Beautiful               | Supplement 2 Quality and aesthetics | | |
| Good Business                | Supplement 3 Health and environment | | |
five dimensions indicate the order of influence of each dimension on a product (Table 5). Specifically, in terms of the evaluation and use of new functions, functionality remained the main influencing factor in screwdriver design. Whether the product is designed to meet the demand of users and is based on a user-centered concept remains the priority in product development. The second major influential factor was comfort, which indicates the essential nature of this factor in hand tool designs. Most people consider that hand tools should be functional and also comfortable to use. The high ratings for professionalism, safety, and usability indicate that users have positive feedback on the additional new functions (i.e., the lighting, and alignment system). Accordingly, the fine operation-aid screwdrivers were inferred to have commercial value. The importance and level of influence regarding the five dimensions decreases from functionality to usability.

4. Conclusion

This study examined the development model of a mature product with relevant ID research, the screwdriver, and conducted further research. The aim was to search for a development method that retains the original functions and design factors of a mature product while adding new functions to the existing products, thereby providing the mature product with new functions. The established fine operation-aid screwdriver evaluation scale revealed that the core values of ID, namely functionality and comfort, remains the priority in design among all dimensions. This again affirms the results of relevant research stating that inclusive accessibility and functionality are crucial in hand tool designs (Lin & Wu, 2015; Wu et al., 2016). However, design principles may change with the adjustments made to the properties of a product. The current results may serve as a reference in product development for designers. Furthermore, the researchers again verified the application of ID to fine operation-aid development models. This study incorporated the concept of ID in product development, making ID more than just a post-design evaluation instrument; this process ensures that products meet ID requirements at the initial stage of design and reduces development time and cost.

Declarations

Author contribution statement

Wei Miao: Analyzed and interpreted the data; Wrote the paper.
Kai-Chieh Lin: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.
Wan-Yu Liao: Performed the experiments.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest’s statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Appendix A

Evaluation scale for fine operation-aid screwdriver

1. This product is designed with users in mind
2. It’s a product you want to own
3. This product can be used in different environments
4. This product is easy to use
5. This product is easy and simple to operate
6. This product takes into account the fairness of different users
7. I don’t need to be taught how to use this product
8. You won’t feel tired using this product
9. This product feels very durable
10. This product is necessary for life and can improve the quality of life
11. The material of this product is suitable
12. This product is designed for different screwdriver users
13. This product can be used by most age groups
14. The design of this product is very reasonable
15. There is feedback in the operation of this product
16. This product can meet the needs of users
17. This product conforms to the common practice of using related products
18. This product is beautiful
19. This product will not cause health effects
20. This product is highly functional
21. This product is marketable
22. This product works better than the previous one
23. The product is simple in structure
24. I can understand the design features of this product
25. This product makes me feel new value
26. This product works very well
27. This product is comfortable to hold
28. This product is of high quality
29. This product can help accomplish the task
30. This product has a good tactile feel
31. This product is not easy to slip
32. Use of this product will not cause hand strain
33. The grip shape of this product is easy to apply force
34. The weight of this tool is very suitable
35. This product is easy to carry
36. The design of bite pattern of this product is excellent
37. This product is not sticky when held
38. This product has a durable grip
39. This product has a nice shape
40. This product looks professional
41. The overall design of the product is excellent
42. There are not too many invalid parts in this product
43. This product can be tested to see whether it is good or bad
44. This product clearly communicates the design of the product
45. This product feels that it has been repeatedly designed and evaluated
46. This product is not sharp
47. This product will not cause sweat on the hands
48. Do you think this product meets the concept of ID?
49. I like this product

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