A tangible learning application from the 3D printer for the practical teaching of meat cutting in inclusive vocational education.

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Abstract. Vocational education and training in Germany are distinguished by the separation of training groups of different learning levels. In chef training, theoretical teaching content is mainly conveyed using lectures and textbooks. The abstract presentations and texts are not suitable for inclusive education. By pursuing a design science research process, a digital-analog learning application was developed for trainees with and without mental impairment. The tangible prototype for teaching meat cutting from pork was evaluated using 7 participants (trainee chef, trainee kitchen assistants and employees in the kitchen of a sheltered workshop) in an inclusive teaching setting with a mixed-method approach. The usability was evaluated with a User Experience Questionnaire, the results of which were positive. The learning outcomes using the 3D model were surveyed by means of a qualitative questionnaire and showed a high level of potential among all target groups. Two unstructured classroom observations documented the social interaction of the trainees. The learning application facilitates learning and promotes collaborative work.

Keywords: Inclusive Vocational Education, Interactive Learning, Game-based Learning, Serious Games, 3D Printing, Rapid Prototyping.

1 Introduction

With the ratification of the UN Convention on the Rights of Persons with Disabilities in 2009, Germany committed to implementing equal opportunities and participation at all levels for people with disabilities and to preventing discrimination [1]. Article 24 calls on States Parties to ensure an "inclusive education system at all levels and lifelong learning" [2]. Article 27 focuses on the "equal right to work of persons with disabilities" [2]. Both the German Vocational Training Act (BBiG) and the Handicrafts Code (HwO) require that people with disabilities be trained in the general dual system, which features a direct connection between vocational schools and training companies as learning locations [3]. The practical implementation, however, features substantial deficits [4]. The legal foundation contrasts with the often-rigid structures of the education system, which is characterized by segregated learning of trainees and people with learning disabilities to the point of the clear separation of people with intellectual disabilities (PWD) [5]. More than 90% of the students with mental impairment start working in sheltered workshops (SW) after leaving school, and these do not offer qualifications for access to the general labor market [6]. The employment rate from SW to the general labor market is less than one percent [7]. According to §66 of the Vocational Training Act, people with learning disabilities are offered less theoretical training to become kitchen assistants [8]. "Inclusive vocational training could be broadly described as the right of PWD to participate in vocational education in a recognized training occupation, to be provided in shared learning facilities with people without disabilities." [9].

This study examines how theoretical learning content can be conveyed in a practical and inclusive way with the help of learning technologies using the example of training to become a chef. New teaching formats, methods and inclusive teaching materials are needed to bring together the three training groups of trainee cooks, kitchen assistants and kitchen staff in sheltered workshops to implement inclusive vocational education [10]. Digital technologies offer great potential for improving equal participation and reducing barriers to access [10]. The development and design of digital learning applications for PWD usually focus on specific groups, e.g. blind or deaf people. People with intellectual and mental impairments, on the other hand, are given little consideration in current research [11]. Serious Games in particular are usually developed for people without impairments instead of following a "design for all" approach. Using Serious Games in the classroom can help to convey theoretical knowledge in a playful way while addressing different cognitive abilities and impairments [11]. Using a design science research process, a haptic, digital-analog learning application was developed for trainees with and without intellectual disabilities [12].

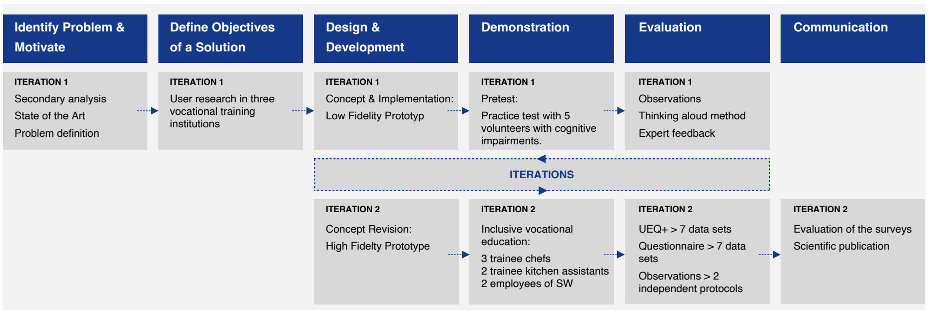

Fig. 1. Design science research process according to Pfeffers et al [12].

In order to analyze requirements, user research was conducted in three institutions of vocational education (Oberstufenzentrum Prignitz, BBZ Berufsbildungszentrum Prignitz GmbH and Lebenshilfe e.V. Prignitz). In the first iteration, a low-fidelity prototype was created, which was evaluated by employees of the SW. The results provided the basis for the conceptual development of a functional high-fidelity prototype. The digital-analog learning application was then evaluated with 7 participants (chef trainees, kitchen assistants and employees of an SW) in an inclusive classroom setting using a mixed-method approach consisting of qualitative and quantitative methods [13]. The standardized User Experience Questionnaire (UEQ) was used to assess usability aspects of the learning application [14]. Additionally, a qualitative questionnaire was used to collect data on learning success and increased motivation through the use of the prototype. Two independent, unstructured, and non-participatory observations in class documented the social interaction and cooperation of the trainees as well as the development of solution strategies. The aim was to use gamified and hands-on concepts to teach theory in a sustainable way, to include all learners by differentiating the teaching content and to increase the interaction between trainees in inclusive lessons.

2 State of the Art

A literature review was aligned with the propositional inventory method [15], [16]. For searching in Google Scholar, IEEEXplore and dblp.org, the keywords selected were 3D printing, vocational training or vocational education, and disabilities or impairments. The search was conducted including synonyms and related terms in German and English. The review of the articles describing concrete applications shows that to date only assistive projects in the field of physical disabilities (16 publications) have been published in the analyzed field, and in particular on severe visual impairments (9 publications). 3D printing now plays a major role in the context of prosthetic prototyping for physical deficits such as amputations, which originated, for example, in the co-creation of developers and PWD in inclusive makerspaces [17]. No publications were identified that used haptic learning or 3D printing for PWD in inclusive learning scenarios. However, upon expanding the search to other educational domains, numerous papers were found that used 3D printed objects to better communicate knowledge and save resources, for example, in veterinary medicine [18]. In human medicine, 3D printing has already been used and researched as a learning tool for around 10 years [19]. 3D printing offers the option of fast reproduction from current or historical 3D data (e.g. MRI, CT) for many learners at the same time, which has also led to less reliance on human plastinates in anatomy teaching. The advantages of tangible learning objects from the 3D printer described in the literature can now be combined with the possibilities of reduction and simplification of anatomical models in such a way that easily understandable anatomical objects are created for inclusive teaching, e.g. for meat cutting, which also provide cognitively impaired trainees with intuitive, communicative and playful access to training content.

3 Prototype

3.1 Learning Objectives

The learning objectives of the meat cutting topic are an integral part of chef training. Currently, vocational school teaching content is predominantly taught using theoretical methods (lecturing) and abstract graphics from the textbook, "The Young Chef" [20]. The lack of time, resources and raw materials means that real butchered animals are seldom cut. The aim of the learning application is to help trainees to name the parts of the pig correctly, to identify them according to shape and position and to describe how they are cooked.

The constructivist learning culture describes the learning process not in terms of knowledge transfer, but as the independent acquisition of knowledge by learners. Only through one's own experience can practical knowledge be taught in a sustainable way. Three basic principles for student-centered teaching have been identified: (1) a variety of methods with a focus on action orientation, (2) the awareness of the increasing heterogeneity of learners and their individual support through differentiation of the teaching content, and (3) the strengthening of the learners' responsibility for their own actions through opportunities to participate in the design of the learning environment [21]. Instructional content is learned more effectively through independent exploration using the "research-based learning" method [22]. When experimenting in the context of research-based learning, the teacher can support the learning process to various degrees [23]. For this purpose, the teacher's role changes from imparting knowledge to providing support through a gradual reduction of instruction to moderation, which allows learners a steadily increasing degree of autonomy in the learning process [23]. The degree of independence must be adjusted to the needs of the class or, in an inclusive setting, to the needs of the individual learner [23].

First, the learning objectives for the three test groups were defined and elaborated together with trainers and a special educator from the vocational training kitchen at the SW. The "à la Carte" module of regular chef training covers the topics of texture, processing and the cutting up of meat from different slaughtered animals [24]. These animals include mainly cattle, pigs, and sheep. The sub-area of "pork" was selected for inclusive teaching because it is most frequently prepared in German kitchens. The individual learning objectives differ in the amount of knowledge acquired and are determined by the students themselves. Learning objective 1 covers the rough cutting of the pig and the naming of the cuts. For learning objective 2, trainees should also be able to locate and name the offcuts from the fine cutting process, as well as identify pieces of meat by their shape, size, muscles and bones. In addition, they are familiar with the use and appropriate cooking methods for the various cuts of meat. Learning objective 3 is an independent identification of the position and naming of all cuts including alternative terms (e.g. pointed leg = trotter).

3.2 Concept

For the concept of an inclusive learning application, knowledge should be written in simple language and the amount of information should be adaptable [11]. Users with heterogeneous learning levels must not be deterred by the abundance of information [11]. Categorizing information and teaching in several stages with increasing information density is suited to this purpose. To promote interaction and collaboration among learners with different educational backgrounds, different levels of teaching content should not be processed separately. For this purpose, the content is transformed into practical scenarios. The application can be used both for group collaboration and alone for practice purposes. The differentiation of learning requirements is not about developing a separate concept for each of the three target groups (trainee chefs, kitchen assistants and SW kitchen employees), but rather an inclusive teaching experience that is shared by all trainees as a common path. For different learning requirements, needs, and abilities, learning applications should provide infinite levels of difficulty to avoid clustering within the classroom [11].

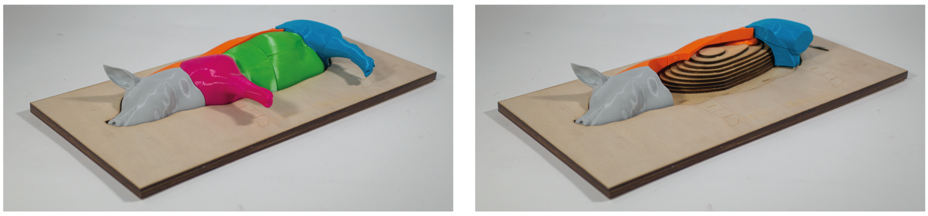

Fig. 2. 3D printed pig in the 5 colors of rough cutting

The learning application includes a 3D printed model of half a pig, a poster and 16 cards to go with it. The poster shows the 5 rough cutting parts on the front and the 16 fine cutting parts on the back. The 3D model consists of a total of 16 parts (fine cutting). There is one card from the set for each part of the pig. The cards contain all the additional information: professional terms, appearance and position of the cut. The back has detailed information about the texture of the meat, alternative names, methods of preparation and possible dishes. On the edges of the poster are colored markers for each piece of pork. The corresponding playing cards are placed on the correct piece on the poster. Then the 3D pieces of the pig are assigned to the corresponding card. If the solution is correct, the colors of the poster, card and 3D part match.

3.3 Implementation

A 3D veterinary anatomical model of a pig was used as the basis for the professional implementation. To extract the meat cuts, the model was adapted in Cinema 4D, Maya and Rhinoceros and, among other things, superfluous organs and textures were removed. The 3D print-out was created using the FDM (Fused Deposition Modeling) rapid prototyping method, as it both conserves resources and is time-efficient. Three Prusa MK3S printers were used for this purpose. To prevent the risk of injury, improve the touch and feel and minimize wear, a flexible thermoplastic elastomer was used as the printing material. Fiberflex filament can be printed at temperatures of 200-220°C and requires a heating bed temperature of 50-70°C. To enable the printed meat cuts to be easily assembled, small neodymium magnets were embedded in the prints. Organs and bone structures were embodied by a supporting base plate made of birch plywood. The volume was represented by the layering of wooden slices created with a laser cutter. In addition, the names and outlines of the meat cuts were engraved on the model. The slices are glued together and painted with wood stain.

4 Evaluation

4.1 Test Setting

The test was conducted in inclusive vocational school lessons at the Oberstufenzentrum Prignitz. Two teachers led the lesson working as a team; a special needs teacher assisted the participants from the SW, and two vocational schoolteachers supported the lesson as inactive audience. A rehabilitation psychologist and an interaction designer conducted unstructured, non-participant observations during testing. Three trainee chefs, two trainee kitchen assistants and two employees of the SW took part in the lessons (n = 7). The class was divided into 3 heterogeneous groups of 2-3 people. First, the basics of the topic of butchery were taught. This was followed by more in-depth information on rough and fine cutting. For using the prototypical learning application, all 3 groups received a task sheet. The cuts of meat, their uses and cooking methods had to be collected and filled in a table with 3 columns. The missing information had to be completed with the help of the learning application. Working groups that were able to solve all tasks were given additional tasks with more difficult questions to be answered with the help of the study cards.

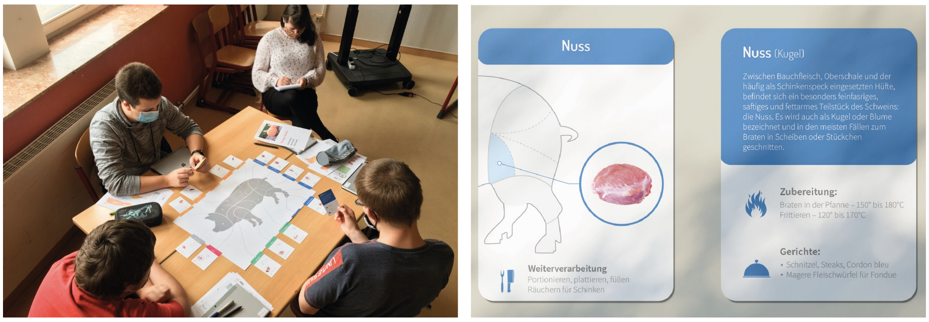

Fig. 3. Testing the learning application in inclusive education; color-coded card set

4.2 UEQ+

The usability of the interactive learning application was evaluated using the UEQ+ standardized test procedure [14]. To evaluate the accomplishment of the objectives, 9 out of 20 available evaluation categories were selected: Perspicuity, Stimulation, Novelty, Haptics, Usefulness, Value, Visual Aesthetics, Intuitive Use and Quality of Content. Each dimension included 4 items consisting of two terms with contrasting meanings (e.g., efficient and inefficient). On a 7-point Likert scale, participants rated the usability aspect very negatively (- 3), neutrally (0) or positively (+ 3). An opening sentence described the context of the respective dimension [25]. There was an additional item with which the participants indicated the relevance of the respective UX dimension for the overall impression of the product.

The mean values of all items surveyed are in the positive range above 0 (between 1.29 and 2.71). The best rating was achieved by the item's clarity of teaching content

(M=2.71; SD=0.45), preparation of the teaching content (M=2.71; SD=0.70), intuitive use of the learning application (M=2.71; SD=0.45) and value of the product (M=2.71; SD=0.45). The lowest scores were given to the item's learning application innovation (M=1.29; SD=1.48), ease of handling (M=1.57; SD=1.99), excitement during the game (M=1.71; SD=0.70), and visual aesthetics of the prototype (M=1.71; SD=0.88).

Table 1. Means for all 36 UEQ+ items (n=7).

UX Dimension	Left item	Right item	M	SD
Perspicuity	not understandable	understandable	1.86	1.64
	difficult to learn	easy to learn	2.29	0.70
	complicated	easy	2.43	0.73
	confusing	clear	2.29	1.03
Stimulation	not interesting	interesting	2.29	0.70
	boring	exiting	1.71	0.70
	inferior	valuable	2.29	0.88
	demotivating	motivating	2.43	0.49
Novelty	dull	creative	2.57	0.49
	conventional	inventive	2.14	0.35
	commonplace	leading edge	2.14	0.83
	conservative	innovative	1.29	1.48
Haptics	unstable	stable	1.86	0.64
	unpleasant to touch	pleasant to touch	2.43	0.73
	rough	smooth	2.43	0.49
	slippery	slip-resistant	2.14	0.64
Usefulness	useless	useful	2.14	0.35
	not helpful	helpful	2.43	0.49
	not beneficial	beneficial	2.00	0.76
	not rewarding	rewarding	2.29	0.45
Value	inferior	valuable	1.86	0.64
	not presentable	presentable	2.71	0.45
	tasteless	tasteful	1.86	1.12
	not elegant	elegant	1.86	0.83
Visual Aesthetics	ugly	beautiful	2.14	0.64
	lacking style	stylish	2.00	0.93
	unappealing	appealing	2.00	0.53
	unpleasant	pleasant	1.71	0.88
Intuitive Use	difficult	easy	1.57	1.99
	illogical	logical	2.57	0.73
	not plausible	plausible	2.71	0.45
	inconclusive	conclusive	2.57	0.73
Quality of Content	obsolete	up-to-date	2.14	0.99
	not interesting	interesting	2.29	0.70
	poorly prepared	well prepared	2.71	0.70
	incomprehensible	comprehensible	2.,71	0.45

It is assumed that the item "demanding - effortless" was not correctly understood by all participants. This pair of terms is an exception in the dimension "Intuitive use". This is also indicated by a strikingly high variance value of 4.62. On average, the dimensions "Quality of content" (M=2.46; SD=0.78) and "Intuitive use" (M=2.36; SD=1.23) received the highest mean values for their four associated items. The dimensions "Visual aesthetics" (M=1.96; SD=0.78) and "Novelty" (M=2.04; SD=1.02) received the lowest overall scores for their associated items.

When assessing the relevance of usability criteria, the dimensions "Perspicuity" (M=2.29; SD=0.70), "Intuitive use" (M=2.14; SD=0.83), and "Quality of Content" (M=2.14; SD=0.83) were rated on average as most important for the evaluation of the SG. The dimensions "Haptics" (M=1.71; SD=0.88), "Visual aesthetics" (M=1.96; SD=1.12) and "Novelty" (M=2.04; SD=0.83) received the lowest mean values. Overall, the evaluation of all 9 scales is in the positive range (> 0.8) and are considered important aspects for the quality of the learning application by the test subjects.

4.3 Survey

All 7 trainees in inclusive education participated in the qualitative survey. With 17 items, the trainees assessed their personal learning successes using the prototype and the acceptance of the inclusive training setting. On a 6-point Likert scale, participants indicated whether they strongly disagreed or agreed with the given statement (1 = strongly disagree; 6 = strongly agree).

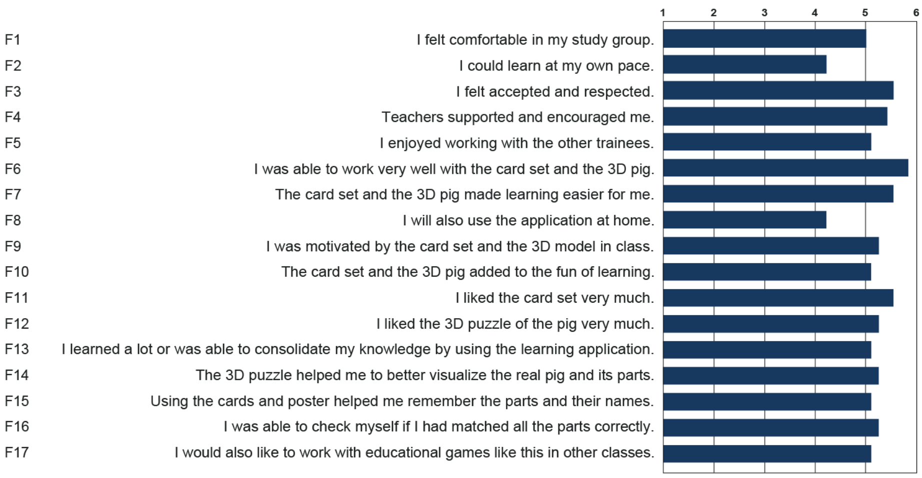

Fig. 4. A figure caption is always placed below the illustration. Short captions are centered, while long ones are justified. The macro button chooses the correct format automatically.

The mean values of all 17 items were above 4 out of a maximum of 6. Accordingly, the majority of participants tended to agree with every statement. The statements F6 "I got along well with the set of cards and the 3D model" (M=5.86; SD=0.38), F3 "I felt accepted and respected" (M=5.57; SD=0.79), F7 "The cards and the 3D pig made learning

easier for me" (M=5.57; SD=0.53), and F11 "I liked the card set very much" (M=5.57; SD=0.53) received the highest agreement. Items F2 "I was able to learn at my own pace" (M=4.29; SD=1.11) and F8 "I will use the cards at home" (M=4.29; SD=1.11) received the lowest level of agreement.
Two further items ask for personal opinions on the realization of the learning application with open answer options. The question "What did you like best about the card set or 3D model of the pig?" was answered by six out of seven respondents as follows: "You had something in your hand and didn't just have to imagine it.", "The vividness of the pictures.", "The 3D pig and the explanations on the cards. ", "You can learn well with it.", "The concepts were easily understood, and the explanations are good.", "It was very nice to look at all of cards and the poster; visually appealing, super prepared, a lot of knowledge in a relatively compact form.”.

Learning material that you can work with very well." There was one answer to the second question, "What did you not like and what would you change about the learning set or the 3D model?", which was, "The magnets in the 3D model are a little weak."

4.4 Observation

Two researchers conducted unstructured, non-participatory observations. One observation focused on the collaboration of a group of three while using the learning application. The second observation followed all of the classroom activities. The observation time covered the entire lesson of 3 x 45 minutes. To evaluate the findings, the observations were divided into four categories: (1) interaction between trainees, (2) learning behavior of the target groups, (3) inclusive didactics, and (4) handling of the learning application.

Interaction between trainees: the game prompted ongoing interaction in the groups. The cards were distributed. To complete the tasks, the participants read out the relevant cards. They actively discussed with each other and searched for the answers. The trainee chef took on a guiding role and pedagogical tasks in the team, such as assigning responsibilities.

Learning behavior of the target groups: the active participation of the participants in the lessons increased when trainees had enough time beforehand to think about the questions and tasks. Compared to the other participants, the employees of the sheltered workshop were more hesitant in the beginning, but they were motivated by encouragement and praise. In terms of content, everyone was able to follow the lessons well. To some extent, the trainee chefs had to make more of an effort to involve all group members to the same degree.

Inclusive didactics: the lesson was taught by two teachers working as a team. In the beginning, the trainees found it difficult to follow the lessons due to the frequent swapping between teachers. In the second half of the lesson, each teacher took over the presentation role for longer periods, which made the lessons more structured. It was helpful if the second teacher was available to advise the groups. However, the teachers should only provide support when needed. It is noticeable that the trainee chefs were addressed more frequently by the teachers. Inclusive teaching requires a high degree of relationship work without prejudices and special treatment. The two vocational schoolteachers commented very positively on the structure, process and content of the learning application.

Handling of the learning application: the teacher used the 3D model to explain rough and fine cutting. Card matching was easy even without reading ability and with increasing complexity. When working on different worksheets, trainees became confused about the order of tasks to be solved. Therefore, structured instructions for handling the application during the lesson are needed. If no differentiated work assignments were given, trainees with higher support needs were unable to follow.

5 Discussion

The analysis of the theoretical foundations in chapter 3 indicates that in vocational education and training too (1) a variety of methods with a focus on action orientation, (2) the perception of the increasing heterogeneity of learners and their individual support through differentiation of the teaching content, and (3) the strengthening of learners' responsibility for their own actions through opportunities to co-design the learning environment are successful. Given this theoretical background, the present study was designed with the aim of promoting the development and research of gamified and hands-on approaches to inclusive, vocational education and training, as well as the sustainable delivery of instructional content in chef training. The differentiation of the teaching content is intended to integrate learners with and without intellectual disabilities and to promote interaction between trainees in inclusive teaching. The overall perception of the learning application was positive across the whole class. In particular, the participants rated the "preparation and quality of the content" and "intuitive use" of the learning application very positively. They confirmed that they "got along well" with the learning application. Despite the fact that the set was developed digitally, once in front of the learners it was not perceived by them to be "technological". In terms of post-digitization [26], the avoidance of a screen-based user interface contributed to the low-barrier nature of the learning application. The qualitative survey made clear that the prototype facilitates inclusive learning, so that new knowledge is acquired and consolidated, and the imagination is improved. The evaluation confirms noticeable learning success from the participant's point of view.

The Serious Game promoted inclusive group work, which increased interaction between trainees, so all participants felt respected and accepted. Two factors need to come together for successful inclusive learning of practical teaching content: good material and qualified teachers for inclusive vocational training. Team teaching proved to be an important motivating factor, with one teacher leading and the other being available to provide individual support. While groups work on tasks and do not actively ask for help, teachers do not need to offer guidance. The social nature of communication between teachers and learners makes learning easier in inclusive classroom settings [27].

The participants agreed least with the statements that they could "learn at their own pace" with the learning application, as well as "would also use the learning application at home". For individual use, the game became effective especially with a concrete work instruction like questions about the information on the cards or placing the cuts of meat. Co-teaching of different educational groups would be more successful if there were differentiation of learning objectives and certified qualifications, as well as suitable applications for acquiring the learning content. A game manual for different purposes with differentiated formulations of tasks could support the promotion of personal strengths in the team (e.g., through role assignment, integration of automated feedback).

Three separate educational systems present a significant challenge in coordinating an inclusive instructional setting in terms of time and space. The trial could only be conducted with a small number of participants, due to logistical reasons as well as pandemic contact restrictions. From the results of the cross-sectional study conducted here, tendencies can be inferred but no cause-and-effect conclusions can be drawn. In addition, it was not possible to identify any accessible, standardized survey methods for evaluating the usability of learning applications and successful learning outcomes in vocational training for people with cognitive impairments. There is substantial potential for future research into and development of inclusive survey tools.

The application supports teachers in inclusive vocational education and can be easily integrated into the curriculum. The analog handling reduces the need for preparation and training of digital competencies, allowing trainees with higher support needs to be involved more quickly. Digital creation enables sharing and adaptation of the learning materials as Open Education Resources (OER). The potential for further development of the learning set can be increased through the simplification of 3D printing hardware and software. Furthermore, the game principle of the 3D application is applicable to virtual space. A virtual reality (VR) learning application holds additional possibilities in vocational education. The use of VR could make a significant contribution to equal participation for special educational requirements in the target group of PWD. However, to date, accessibility, and the perspective of PWD have barely been considered in the creation of VR applications and have not yet been systematically researched [28].

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