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SELECTED CASE STUDIES REGARDING RESEARCH-BASED EDUCATION IN THE AREA OF MACHINE AND CIVIL ASSEMBLIES

WYBRANE ZAGADNIENIA EDUKACJI OPARTEJ NA BADANIACH NAUKOWYCH DOTYCZĄCYCH ZŁOŻEŃ STOSOWANYCH W INŻYNIERII MECHANICZNEJ I LĄDOWEJ

Abstract

The paper presents selected case studies in the area of research and teaching activities focused on technical assemblies. The aim of the work is to discuss the current trends in assembly-related research activities in partner universities of the EDURES project and to present teaching methodology related to the research. Due to the great importance of research-based education for innovative teaching methodology, research utilization into teaching process is addressed in the paper as a priority of modern teaching, which uses digital platforms and is focused on fast dissemination of the research results among both researchers and higher education students.

Keywords: research-based education, assemblies, mechanical engineering, civil engineering

Streszczenie

Artykuł przedstawia wybrane zagadnienia dotyczące problematyki złożeń w obszarze badań i nauczania. Celem pracy jest przedstawienie bieżących trendów badawczych dotyczących złożeń, które istnieją w uczelniach partnerskich projektu EDURES i metodyki nauczania w tym zakresie. W artykule podkreślono duże znaczenie edukacji opartej na badaniach naukowych oraz wykorzystania różnych platform cyfrowych i szybkiego upowszechniania wyników badań zarówno wśród badaczy jak i studentów uczelni wyższych.

Słowa kluczowe: edukacja oparta na badaniach naukowych, złożenia, inżynieria mechaniczna, inżynieria lądowa

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1. Selected challenges of assembly research and teaching

Research in the area of advanced assemblies is conducted in various scientific disciplines. The same fact concerns teaching methodologies. The significant disciplines, among others, that conduct their activities in the area of assemblies are mechanical engineering and civil engineering. The abovementioned sentences are a consequence of teaching and research experience of authors' universities. A link to mechanical and civil engineering is caused by the importance of construction problems and set-ups in various machines and their assemblies, and moreover in different civil objects such as buildings, bridges, steel assemblies, machines useful in civil engineering works. Assembly research has been an important topic of research [22] within the disciplines mentioned above.

Nowadays, assemblies are designed and developed by the use of modern computer-aided design (CAD) software and computer-aided engineering (CAE) software tools. These tools have become standard solutions for engineers and researchers. The two abovementioned disciplines are supported by dedicated software tools that utilize specific algorithms and tools. Software tools accelerate calculations performed by engineers. Software development and its wider utilization in research plays therefore an important role in research and teaching activities. Advanced software solutions such as virtual reality or augmented reality tools enable also improvements of didactic methodologies by elimination of cost, resulting from purchase of machines and physical test stands.

In terms of assembly manufacturing and maintenance processes, great importance should be assigned to combined and complex manufacturing processes including 3D printing technology, robotization of assembly lines, application of various sensors, etc. Manufacturing and maintenance of assemblies is, therefore, shaped by the complex tools and engineering approaches. Mass production of assemblies is nowadays more often replaced by short series and manufacturing research approaches should be, in authors' opinion, focused on complex issues and analyses to achieve sufficient reliability of mechanical products and civil constructions.

Moreover, international research cooperation and data exchange which can be supported nowadays by developing communication technologies resulting from mobile networks and modern methods of communication may be utilized by teachers and researchers for improvement of methodologies.

The above-described areas of research and teaching which are crucial in authors' opinion, are presented in Fig. 1 in a concise form and defined as proposed priorities.

Selected research priorities and examples

I. Software development
- Product assembly development
- CAx supported assembly research
- Artificial intelligence-related apps development

II. Assembly manufacturing and maintenance
- Application of complex processes
- Customized assembly advanced maintenance

III. International research cooperation
- Reserach data exchange by product management systems
- Cloud work
- Mobile work environment development

Research-based teaching priorities

I. PBL (Project Based Learning) classes for assembly development

II. Utilization of research results in teaching
- University research portal development
- Teaching methodologies development
- E-learning contents development

III. International research cooperation of students and teachers
- Common databases (e.g. theses.prz.edu.pl)
- Research discussion teams (e.g. periodical meetings)
- International trainings

Fig. 1. Assembly teaching and assembly research priorities proposed by authors

The main aim of the paper, resulting from the proposed priorities, concerns a discussion regarding current trends in assembly-related research activities in partner universities of the EDURES project and is focused on presentation of teaching methodology related to the research.

The next chapters will focus on the description of the quality of teaching indicators and how assembly-related research could contribute to modern teaching curricula. Moreover, selected case studies regarding assembly-related research will be presented, and their application in teaching will be briefly discussed to present the general state of art to a reader. These case studies will focus on mechanical and civil problems.

The presented discussion and case studies are formulated based on the teaching and assembly-related research experience of separate authors and lead to a unique methodology useful for common teaching processes and further development of common research.

2. Quality of teaching indicators and importance of research implementation in teaching

Teaching/learning quality indicators help teachers and educational institutions measure and improve the quality of teaching activities, leading to improved student performance. These indicators provide feedback on the strengths and weaknesses of the teaching process, which can be used to improve teaching materials and methods. Importantly, the use of teaching/learning quality indicators can help allocate resources efficiently. If a particular teaching method is found to be especially effective, resources should be directed towards broader implementation of that method. By using teaching/learning quality indicators, teachers can also identify ways to better engage students in the learning process, which can improve motivation and thus student performance. Therefore, teaching/learning quality indicators are essential tools to improve education quality and provide students with the best possible educational experience. There are many indicators of teaching and learning quality; some of the key indicators are the following:

1. Graduation rate: Measure the percentage of students who complete their educational programmes. High-quality teaching and a positive learning environment are usually associated with a higher graduation rate. It should be noted that the graduation rate alone does not represent the quality of education; it is possible to achieve a high graduation rate despite poor teaching quality.
2. Student achievement – learning outcomes: the knowledge, skills, and competencies that students acquire during their education. The study [13] showed that high-quality teaching has a significant impact on the achievement rate of the intended learning outcomes. Student achievement can be measured with standardised tests, for example, the Programme for International Student Assessment (PISA).
3. Student engagement: active participation of students in the learning process. The study [11] confirmed that student engagement is positively related to student achievement and is influenced by teacher-student relationships and school atmosphere.
4. Teacher performance: measures how well teachers are able to facilitate student learning and support student achievement. Teacher performance can be assessed through analysis of students' achievement, student surveys, or classroom observations. A report [7] found that effective teacher performance is associated with higher student achievement.
5. Effective teaching strategies: high-quality instructional methods that improve student performance. A study [19] showed that appropriately selected instructional strategies, such as formative assessment, can significantly improve student achievement.
6. Professional development of teachers: refers to ongoing training and development of teachers to expand their knowledge and improve their teaching skills. In the study [8], it was shown that continuous professional development of teachers leads to better student learning outcomes.

Scientific research plays an important role in the education of engineers. Scientific research contributes to the expansion of technical knowledge and enables the learning and application of the latest technologies, methods, and tools for the design and improvement of technical products and systems. Following current scientific research develops creativity, which encourages critical thinking and independent problem solving. Incorporating the issues of current research projects into the curriculum can also help prepare students for careers in engineering. The literature provides many examples that demonstrate the positive aspects of integrating research projects into engineering education, including the positive impact on teaching/learning quality indicators due to the impact on students and teachers.

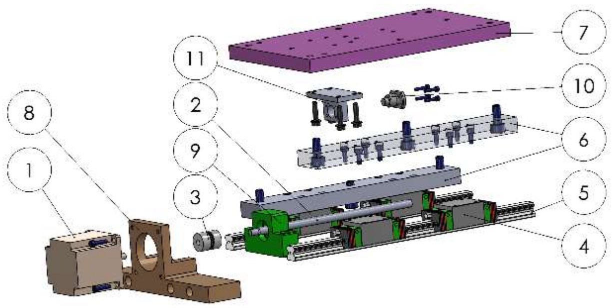
In the analysis of a research-based curriculum for an engineering course [4], it was found that the curriculum had a positive impact on students' achievement, improved knowledge of engineering concepts, and increased their engagement. In the work [24] it was shown that aeronautical engineering students who participated in research-based projects demonstrated better mastery of the course content and greater motivation to learn. The article [23] noted that students who participate in research often have a positive attitude toward their field of study and identify with the academic community. A course structure that includes research experiences can improve student engagement and achievement by connecting course material with real-world challenges [9].

Designing research-based learning activities can help teachers create more engaging and interactive learning environments, which positively impacts teacher performance [24]. Research-based pedagogical approaches can also improve teacher performance by promoting critical thinking, problem solving, and collaboration skills among both teachers and students [2]. A study [23] found that research in engineering education can improve teacher performance by providing professional development opportunities and promoting the use of innovative teaching methods.

The literature examples presented here clearly show that by providing research-based teaching and engaging students in research experiences, engineering teachers can improve their effectiveness while helping students achieve better academic performance.

3. Case study 1: CAD assembly research and general teaching methodology

Advanced CAD/CAM (*Computer Aided Design/ Computer Aided Manufacturing*) software is nowadays one of the most significant digital tools (CAx) of the digitalized manufacturing industry. Regardless of their function as independent software or modules of extended CAx platforms, they have become important tools for manufacturing environments [28]. CAD systems are useful for the design of parts characterised by various shapes, assembly design (Fig. 2), visualisation of products, technical documentation preparation, prototyping, etc. Modelling complex geometries using CAD tools, including assemblies, is quite a complex task. However, it allows to develop product effectively in a virtual environment leading to cost reduction (complex parts may be developed without necessity of prototypes manufacturing). Another issue concerns the simulation in the CAD environment. It may accelerate R&D work. Advanced software solutions such as assembly work simulation or various kinds of analysis allow for the elimination of costs resulting from the purchase of machines and physical test stands.



1	stepper motor	5	linear guide	9	bearing housing
2	drive screew	6	mounting plates	10	drive nut
3	clutch	7	support	11	drive nut holder
4	linear carrier	8	stepper motor holder		

Fig. 2. Exemplary research in the area of assembly design

The teaching process at higher education level regarding CAD product development may be inter alia based on a problem-based learning approach (PBL). Students may be asked to develop different product variants in CAD on the basis of initial assumptions, perform simulations, discuss pros and cons, and decide on the final product variant based on the defined indicators of product quality. This approach allows students to be involved in team work and also appreciates their own developments because various product variants may be developed by a single student or in very small groups. In this case, the final evaluation of every student is also reachable.

4. Case study 2: Civil construction assembly research and teaching methodology

The greatest potential in the development of civil engineering in the context of designing and assembling objects is the development of BIM (*Building Information Modelling*) technology. It allows for streamlining of the investment process for the benefit of all participating entities: investor, designer, contractor, supervisor, administrator, and user. The implementation of BIM technology will enable better (cheaper, faster) construction of buildings. The main requirement of this approach is working with a common 3D geometric model. Such a model, in addition to consistent information about the geometry model, should contain additional non-graphical data. Such data extend the knowledge about the implemented investment with current bills of materials, schedule, cost estimate, environmental impact assessment, and information for the facility manager. As part of the project, the method of assembly of all structural elements and equipment must be specified. The main advantage of such an integrated design process is the ability to coordinate the design work of all disciplines (e.g. architecture, construction). Working on the basis of a shared 3D model allows to eliminate the number of collisions that can be identified already at the design stage. This enables a reduction of errors measurable in terms of cost and time. This approach is not new, because it is successfully used in the electromechanical industry. Currently, the construction industry is trying to emulate the production process management solutions adopted there, including assembly aspects. The basic limitation of the implementation of these solutions in the construction industry is the specificity of the building objects. Most of the buildings are unique or made in small series. Serial production related to the construction industry consists of components from manufacturers of building materials. Aspects of assembly requirements in civil engineering are different and are primarily related to construction technology in the context of the construction materials used (concrete, steel, ceramics, wood). An additional aspect is the proper use of additional elements (scaffolding, formwork, connectors) as well as tools and equipment. Currently, each of the design phases is supported by computer techniques (CAx). There are suitable applications available on the market from many software manufacturers in narrow industry ranges. These software tools allow you to build geometry models of objects, perform design analyses, prepare executive documentation, and control the manufacturing and building erection process. The basic problem is data exchange between programs and their integration. The reasons for this phenomenon are mainly due to the protection of the intellectual property of software producers. The solution to this problem may be the unification and standardization of the construction process, which is being implemented in developed economies (USA, Germany, UK). In addition, the development of information technology resulting in an increase in hardware and software performance allows for modelling more complex objects containing more and more information.

Research problems in the field of construction cover a very wide spectrum of fields. Part of the research related to the aspect of assembly is related to the collision-free shaping of geometry. Parametric modelling applications are helpful in this regard. These programs use visual programming to generate entire families of models driven by input parameters (width, height, number of storeys, etc.) [3]. This approach allows for the analysis of a larger number of versions of the designed object. As part of the software, we can introduce additional geometric constraints (e.g. perpendicularity, parallelism, length) to the model. Such approaches support the work and expand the workshop of modern civil engineers.

Another challenge is the implementation of these solutions in the education process. In the context of these changes, the use of computer techniques for teaching effects is being intensively introduced in the construction industry. For example, EDURES project partner already uses 3D modelling software (Revit Autodesk) in the first-degree studies stage. By modelling simple building objects, students learn how to properly shape geometry. They practice the element of cooperation by working with a central (reference) model. This increases the awareness of co-responsibility for the created model, which is later to be built (assembled). Second-degree students who already have substantive knowledge carry out tasks related to parameterization and data exchange between programs. For example, a student creates a parametric geometric model of a steel structure in Revit Autodesk. Then export (Fig. 3) the data and perform strength verifications in the FEM (*Finite Element Method*) analysis program. The verified model is imported into the Advance Steel Autodesk program, where it prepares detailed design documentation. Such documentation takes into account all aspects of assembly (division into elements and the order of their connection). This software allows to prepare data for NC machines used in the production of steel elements. In another education module, students practice a wider range of elements of BIM technology. A joint project carried out in groups of four includes the following aspects: shaping the geometry, performing strength analyses, detailing steel and reinforced concrete, searching for collision with another industry project, preparing a schedule and cost estimate, preparing a visualisation of the facility and animation of the assembly of the structure. Execution of the project requires students to be able to negotiate the division of the scope of work into stages and to establish a plan for their implementation. The project is very complex and laborious. However, it prepares the student to work in the contemporary realities of modern construction.

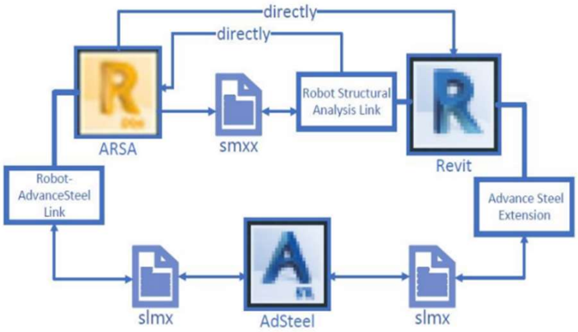


Fig. 3. Data exchange in Autodesk software tools

5. Case study 3: Research on measurement of advanced assemblies and teaching methodology

Measurements of parts of assemblies that can be found in machine industry can be carried out by means of various advanced contact and non-contact coordinate measuring systems [21, 29] e.g., coordinate measuring machines (CMMs), measuring arms and CNC machine tools equipped with scanning measuring probes. The selection of a measuring system to a measurement task depends, among others, on the shape of an investigated product, tolerances of measured parts, and time of coordinate measurements. CMMs are still the most universal and therefore very popular measuring systems [29].

The accuracy of measurements of assemblies conducted by using coordinate measuring machines depends on many elements. The review of factors that determine the uncertainty of coordinate measurements is presented in the work [20]. One of the above-mentioned factors is the measurement strategy including e.g., measurement speed, number and distribution of measurement points, filtration parameters, position of a measuring probe in relation to a measured product and exposure time when using non-contact measuring probes.

Coordinate measurements of elements of assemblies performed by means of CMMs are possible thanks to metrology software enabling measurements of e.g., products characterised by regular geometric shapes, parts composed of curvilinear surfaces, gears, and turbine blades. Metrological software may include different methods of e.g., the probe radius correction process and methods of distributing measurement points. The issue of calculating the coordinates of corrected measurement points has been addressed in many papers e.g., [1, 18]. The very well-known producers of coordinate measuring systems are the following companies: Carl Zeiss and Mitutoyo. Erkan et al. [10] presented the possibilities of two software packages of the companies mentioned in the field of the probe radius correction process.

Fig. 4. Metrological assembly used in modern research and teaching activities

The coordinate measuring technique should be taught at technical universities to increase the accuracy, efficiency of measurements and awareness of the existence of many factors determining measurement results. Moreover, knowledge in the field of the metrology of geometrical quantities may lead to a reduction in the time of coordinate measurements conducted under industrial conditions. The subject 'Coordinate metrology' should be divided into lectures and laboratories. During lectures, students should acquire knowledge regarding e.g., fundamentals of the considered technique, stages of coordinate measurements, factors influencing results of measurements and the uncertainty of measurements. In the case of laboratories, they should learn to operate coordinate measuring systems and metrology software cooperating with e.g., CMMs. They may use off-line versions of software packages to create and simulate programs controlling measuring systems. Selected programs, created and checked by students, may be run on a real machine. Labs should concern measurements of real products of machine industry.

Exemplary metrological assembly that can be used within both research and teaching activities is presented in Fig. 4.

6. Case study 4: Gluing

Lectures and laboratories are devoted to the assembly process in the field of mechanics and machine construction in the subject fundamentals of machine technology and in the field of mechatronics in the subject of manufacturing engineering. As part of the subject matter, special attention is paid to gluing operations, thanks to the possibility of getting to know the essence of the process in practice. During the classes, it is possible to observe the course of gluing, in which surface preparation operations play an important role. Methods and effects of surface preparation before applying the adhesive are discussed, i.e. cleaning of corrosion and paint layers, degreasing and washing, shaping the surface a specific roughness and geometric structure. The influence of conditions and preparation technology on the final strength of the joint is analyzed. As part of laboratory classes, glued joints are made in various variants distinguished, among others: due to the method of surface preparation selected for a specific type of material (sandblasting, sandpaper, laser, by galvanic treatment), type of glue (e.g. epoxy, methacrylic, cyanoacrylate and others), method of preparing the adhesive mixture (single or two-component, mixed in the nozzle of the manufacturer's packaging or manually according to the adopted proportions), method of connection construction (single-lap joint, butt joint), overlap size and others. Connections are tested, inter alia, for static resistance to tearing. When working with students, studies by researchers from other research centers are used [25, 26] as well as publications of own research results [5, 6].

Figures 5 and 6 present examples of used adhesives and test samples (lap joints). The subject is of great interest among students. There are also diploma theses on the subject of assembly, in which the independent implementation of experimental research is a task focused on industrial applications, due to the emergence of new construction materials and adhesives.

Fig. 5. Examples of adhesives used

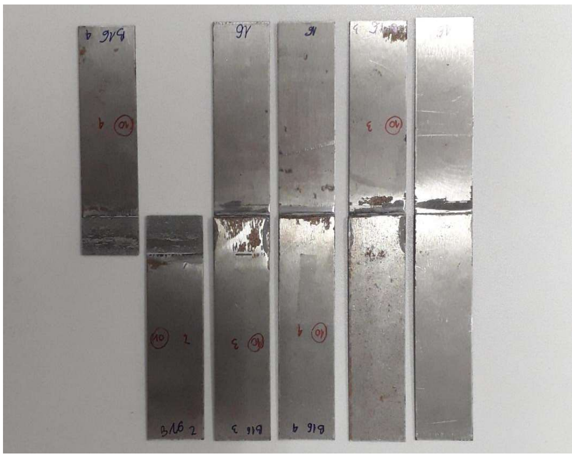


Fig. 6. Test samples – single-lap joints

7. Case study 5: Electro discharge machining process (EDM) utilization for manufacturing of precise assembly parts of machines

The following section pertains to a brief presentation and discussion regarding the non-conventional process of Electrical Discharge Marching (EDM). EDM is one of the earliest but still widely employed thermo-electrical process, which is mainly utilized in machining electrically conductive materials. The basic operation principle of EDM is considerably simple, as the material is removed through a number of rapid repetitive spark discharges in the presence of dielectric fluid. More specifically, a voltage difference is applied between an electrode and the workpiece, which typically are both submerged in a dielectric fluid and at a very close distance, but not in touch. Under the act of the voltage difference, an intense electromagnetic field is developed. At some point, most commonly where the two materials have the minimum in-between distance, the fluid's dielectric constant breaks down, causing a spark and forming a plasma channel. Topically, extremely high temperatures develop in the range of 6,000 - 12,000°C, resulting in the melting and / or ablation of the material. With the end of the voltage pulse, the plasma channel is collapsed; the melted and ablated material is removed due to the presence of the dielectric fluid and finally, the system returns to its initial state in order for a new cycle to start. The aforementioned general cycle is repeated thousands or even millions of times per second, resulting in the gradual removal of small material volumes. It is also important to note that, during the process, only an amount of melted material is removed by the workpiece, the rest being resolidified and forming a layer of amorphous material on the top of the workpiece, known as the White Layer [15].

In the relevant literature, several different process parameters have been studied and discussed to improve process quality and efficiency. In general, the most widely employed performance indexes that are commonly utilized to assess the process are the Material Removal Rate (MRR), which pertains to the material removal volume per minute, the Tool Wear Ratio (TWR), which depicts the wear of the working electrode in respect of the MRR, the Surface Roughness and finally the Surface Topography and the Surface Quality. It has been proven that all the above performance indexes are directly and strongly related to the process parameters and especially the electrical pulse characteristics, e.g., the pulse duration, the time between two successive pulses, the voltage difference, and the current density. Thus, it is scientifically interesting, but also with practical value, the in-depth understanding of the process and the underlying mechanisms, along with the further study and research concerning the process optimization. Moreover, modelling and simulation methods can be deployed in order to further study and optimize the EDM process. As an example, in Fig. 7 representative results of the EDM process are presented concerning the material removal and the temperature field in the electrode and the workpiece during a single spark [14].

Finally, from the perspective of engineering assemblies and their quality, the study and optimization of EDM process and its performance indexes, is a very important issue considering that the dimensional accuracy, the surface roughness, the surface topography and the surface quality, depend on the definition and use of proper and optimal machining conditions and parameters. Therefore, in the literature, many significant and relative studies can be found. As an example, in the work of Karmiris - Obratanski et al. [17] an extensive study has been conducted regarding the surface and subsurface quality of Titanium Grade 23 after its machining with EDM. In another similar study, the optimalization of the surface texture and machining parameters of 60CrMoV18 steel after EDM has been investigated and discussed [16]. In the work of Gong and Sun [12] a study concerning the forming consistency and accuracy in fabricating array micro-electrodes and array micro holes using EDM is presented, while in another representative example, the machining parameters of wire-EDM are optimized aiming in maximum surface hardness and minimum dimensional deviation after the process [27]. The references above clearly indicate the direct and strong correlation between the machining parameters and the obtained results regarding the quality of an engineering assembly, which all or some of its components have been manufactured utilising the EDM process.

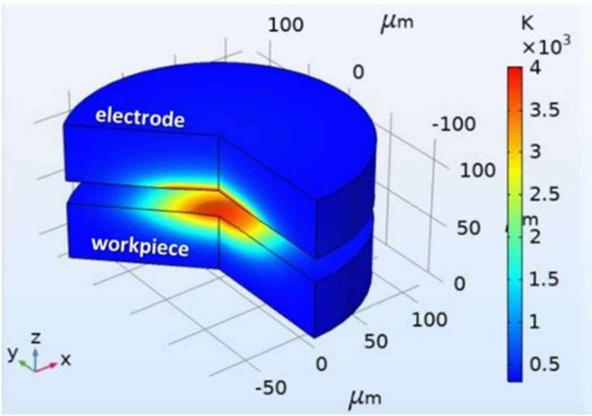


Fig. 7. Simulation results of the EDM process for the electrode and the workpiece regarding the material removal and the temperature field during a single spark

8. Case study 6: The use of advanced assemblies in measurements of machining processes indicators and teaching methodology

In the Institute of Precision Machining (KSF) at the University of Furtwangen, several research every year are conducted in machining, grinding, laser processing, simulation and Artificial Intelligence (AI). These research activities allow students to translate their effective knowledge (obtained in theoretical lectures) into practice. Students can involve in these research activities through their bachelor, master, or project work. For conducting research activities, several measuring devices are available for in situ and in process measurement. Therefore, students can use them to practically study the effect of different parameters on the measuring outputs and analyze the machinability of different materials. For example, the generated forces are one of the most important factors for evaluating the machining process. In this regard, the students are provided with a multi-component force measurement system (Kistler) for measuring and analyzing the cutting forces in different directions. The force component measuring device (or dynamometer) is available in different sizes. Figure 8a indicates an experimental setup for performing the micro-machining process and measuring the cutting force with a dynamometer in the machine tool. Furthermore, the ImageIR 8300 thermography camera (InfraTec) is used for temperature measurement during machining, as illustrated in Figure 8b. In addition to in situ measuring devices, the integrated confocal microscope in the machine tool allows for analyzing the machined workpiece (See Figure 8c). Moreover, portable tactile surface roughness measurement is used for the in-process measurement in the machine tool to measure surface roughness.

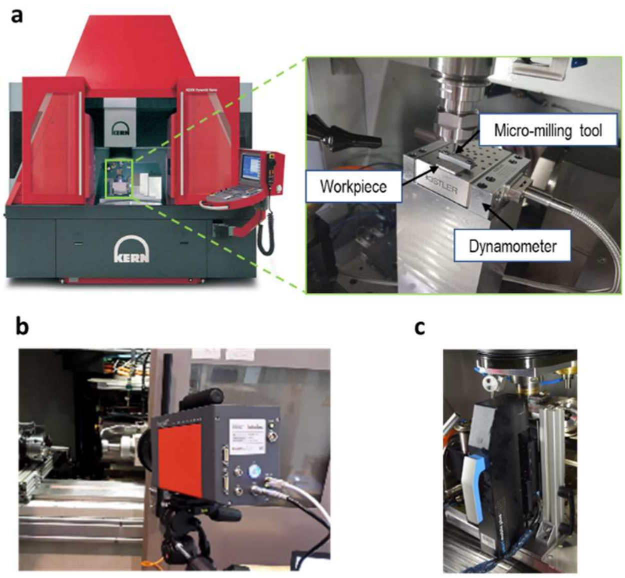


Fig. 8. Exemplary integrated measuring devices into machine tools. a) dynamometer, b) thermographic camera, c) confocal microscope

Moreover, the students in their research activities can benefit great deal from modern device for measuring and analysis of the process. A five axes CNC machine tool (Haas-Multigrind® CA) with a Siemens Sinumerik controller is used in different research studies. For the data acquisition, the machine tool is equipped with a so-called Siemens SINUMERIK EDGE (SE) Box (Fig. 9). Siemens CNC controls supply data, and SE, make it possible to record data and states of the control in a resolution of 1 ms (1kHz) parallel to the process. The SE box is, in principle, an industrial computer and has the corresponding resources to store the data. The MindSphere Capture4Analysis application enables the selection of the signals to be recorded and the trigger time from which a signal is to be recorded. According to a defined system, the data is written to a JSON file on the hard disk of the SE box with the execution of the NC program. Further, the JSON File for each test is processed through a written ETL program (Extract-Transform-Load) to obtain the tabular data in CSV format. The CSV data and post-process information from the measurement system collected in tabular data are used for further analysis.

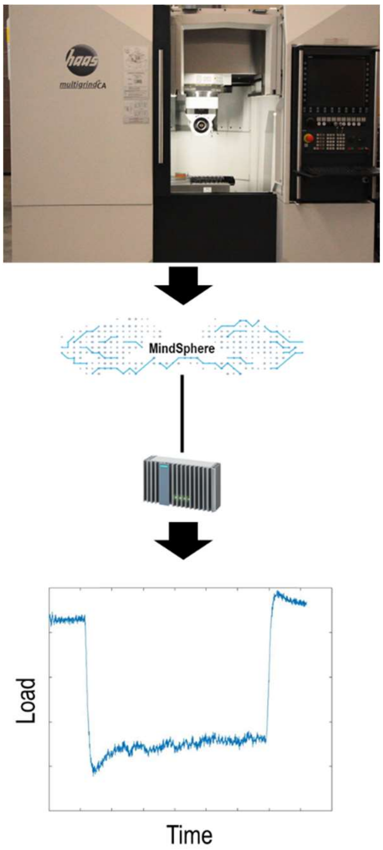


Fig. 9. In Situ measurement of load using Edge-Box

9. Conclusion

Case studies regarding research-based education in the area of advanced assemblies were presented. They reveal that research-based education can be focused on various topics in the area of assembly technology which is a current issue of research and teaching environments of partner universities of the EDURES project. The EDURES project partners have developed a methodology which is based on their research interests that supports the implementation of research results in teaching and allows for a wider discussion and further developments in this area. Based on team work effects it is visible that understanding of research based education is not understood similarly and transparency of research is a main problem which should be addressed in future analyses.

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References

1. Ahn H.K., Kang H., Ghim Y.-S., Yang H.-S. 2019. “Touch probe tip compensation using a novel transformation algorithm for coordinate measurements of curved surfaces”. *International Journal of Precision Engineering and Manufacturing* 20: 193-199.
2. Bezanilla, M.J., Fernández-Nogueira, D., Poblete, M., Galindo-Domínguez, H. 2019. “Methodologies for teaching-learning critical thinking in higher education: The teacher’s view”. *Thinking skills and creativity*, 33, 100584.
3. Borowiec, A. 2023. “Dynamo Studio - an effective tool to support the civil engineer workshop for parametric modeling of structure geometry (in Polish)”. *Inżynieria i Budownictwo* 1-2.
4. Borrego, M., Bernhard, J. 2011. “The emergence of engineering education research as a globally connected field of inquiry”. *Journal of Engineering Education* 100 (1): 14-47.
5. Ciecińska, B. 2020. “Using Lasers as Safe Alternatives for Adhesive Bonding: Emerging Research and Opportunities”, IGI Global, USA, 1-248.
6. Ciecińska, B. 2022. “Experimental studies of the possibility of laser processing as a cleaner method of achieving a surface with good adhesion”. *Production Engineering Archives* 28(3).
7. Darling-Hammond, L. 2010. “Evaluating teacher effectiveness: How teacher performance assessments can measure and improve teaching”. Center for American Progress.
8. Desimone, L.M. 2009. “Improving impact studies of teachers' professional development: Toward better conceptualizations and measures”. *Educational Researcher* 38 (3): 181-199.
9. Eddy, S.L., Hogan, K.A. 2014. “Getting under the hood: How and for whom does increasing course structure work?”. CBE-Life Sciences Education 13 (3): 453-468.
10. Erkan T., Mayer R., Woźniak A. 2011. “Surface probing simulator for the evaluation of CMM probe radius correction software”. *The International Journal of Advanced Manufacturing Technology* 55: 307-315.

11. Fredricks, J.A., et al. 2004. “School engagement: Potential of the concept, state of the evidence”. *Review of Educational Research* 74(1): 59-109.
12. Gong, S, Sun, Y. 2022. “Experimental study on forming consistent accuracy and tool electrode wear involved in fabricating array microelectrodes and array micro holes using electrical discharge machining”. *J Manuf Process* 79:126-141. https://doi.org/10.1016/j.jmapro.2022.04.046.
13. Hattie, J. 2009. “Visible learning: A synthesis of over 800 meta-analyses relating to achievement”. Routledge.
14. Jahan, M.P. 2015. *Electrical Discharge Machining (EDM): Types, Technologies and Applications*. Nova Science Publishers, New York.
15. Jameson, E.C. 2001. *Electrical discharge machining. Society of Manufacturing Engineers*, Michigan.
16. Karmiris-Obratański, P., Papazoglou, E.L., Leszczyńska--Madej, B., et al. 2022. “An Optimalization Study on the Surface Texture and Machining Parameters of 60CrMoV18-5 Steel by EDM”. *Materials (Basel)* 15:3559. https://doi.org/10.3390/ma15103559.
17. Karmiris-Obratański, P., Papazoglou, E.L., Leszczyńska--Madej, B., et al. 2022. “Surface and subsurface quality of titanium grade 23 machined by electro discharge machining”. *Materials (Basel)* 15:. https://doi.org/10.3390/ma15010164.
18. Kawalec, A., Magdziak, M. 2017. “The selection of radius correction method in the case of coordinate measurements applicable for turbine blades”. *Precision Engineering* 49: 243-252.
19. Loughland, T., Kilpatrick, L. 2015. “Formative assessment in primary science”. *Education* 3-13, 43: 128-141.
20. Magdziak, M. 2022. “Estimating Time of Coordinate Measurements Based on the Adopted Measurement Strategy”. *Sensors* 22: 7310.
21. Mehrad, V., Xue, D., Gu, P. 2014. “Robust localization to align measured points on the manufactured surface with design surface for freeform surface inspection”. *Computer-Aided Design* 53: 90-103.