p-ISSN: 2184-044X e-ISSN: 2184-1489 ISBN: 978-989-35106-4-3 © 2023
https://doi.org/10.36315/2023v2end011

# AN APPROACH TO GAME-BASED LEARNING, COLLABORATION AND DESIGN CHALLENGES FOR TEACHING THE DESIGN OF MECHATRONIC SYSTEMS

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## Abstract

In this paper, the teaching of a methodical design approach for mechatronic systems is presented. The students are collaborating in teams and must design and build a real prototype for a robot that carries a fragile load and is entered into a final contest at the end of the course. Applied teaching principles include game-based learning with Moodle quizzes, design challenges to engage with the students and weekly theoretical lectures linked with practical sessions that include the use of mechanical construction kits, CAD design and rapid manufacturing using 3D printing. The project is time-boxed and organized according to the methodical framework of the guideline VDI 2221.

***Keywords:*** *Game-based learning, collaboration, design challenges, constructive alignment, methodical design approach.*

## 1. Introduction

In today's world, developing new products is more complex than ever. Conflicting goals of product cost, quality and limited time as well as post-pandemic part shortages increase the difficulty. Due to the inherent complexity of mechatronic systems, students very rarely have enough time in one semester course to experience a complete design approach, starting from planning, designing up to the manufacturing of a prototype and its testing. But, for students to be successful in the industrial world, it is crucial to know how to use design frameworks in a time-efficient way and how to maneuver upcoming problems and conflicts. Therefore, teaching the design of mechatronic systems under real-world conditions is a necessity to improve important skills of students (Bender 2012).

This paper proposes a teaching approach which challenges the students with a given design task under the following boundary conditions: open solution space, limited time of 4 months, fixed cost budget of 150€ per team, inherent complexity of the product, sudden part shortages, a realistic collaboration setup and the usage of rapid manufacturing as production means.

## 2. Design project and teaching approach

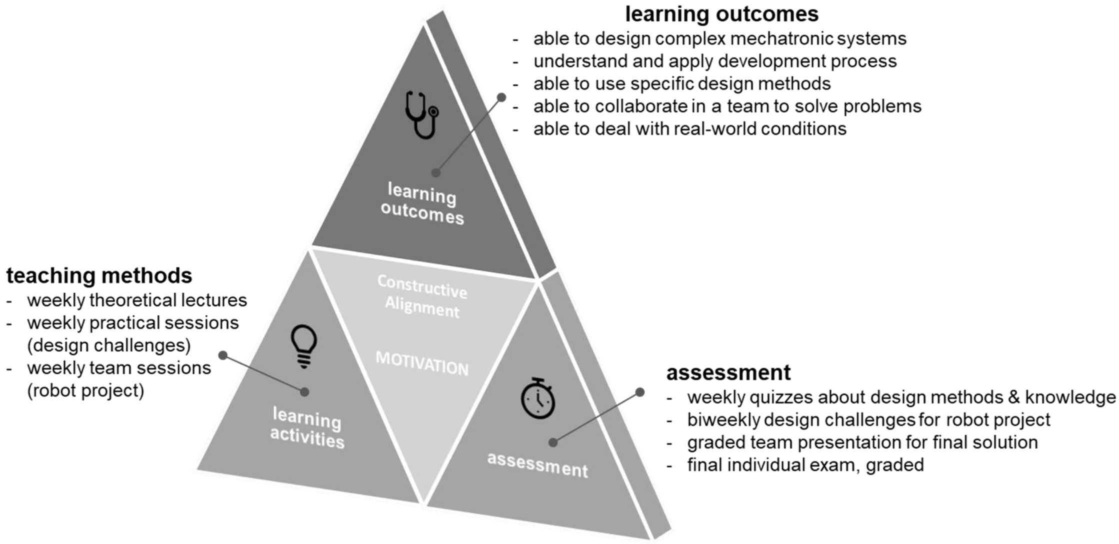
The goal of the chosen mechatronic project is to develop a remote-controlled robot, which operates on flat surfaces with inclines of up to 3° and carries a fragile load. It should be able to interact with other robots and manipulate their fragile load while protecting its own load, i.e. it can support up to one offensive / defensive function. The students collaborate in teams with up to 6 members and are graded based on their team effort at defined milestones. The final goal is to manufacture and assemble a working prototype which is tested by entering a 1vs1 contest against other robots. The specified requirements are maximum build space of 250x250x200mm, a design budget of 150€, the usage of predefined electric actuators and electric batteries with a fixed capacity (due to safety), a maximum weight of 2 kg for the complete robot, no metal parts in the offensive/defensive functions, no possible harm in human interactions and no usage of projectiles. Apart from that, the solution space is completely open and can be explored by the students.

From a teaching perspective, a methodical design approach inspired by the guideline VDI 2221 with preset milestones is combined with game-based learning and biweekly design challenges. Weekly lectures, which cover the theoretical input for each phase, are accompanied with weekly practical sessions, in which the teams apply the new knowledge on a concrete design challenge for their robot. Every two weeks, the teams must turn their results in for examination. Following a game-based learning approach, each lecture is also accompanied by a multiple-choice test, which can be taken at any time at any place and quizzes the students about their level of understanding. These quizzes are automatically graded and award a new badge in Moodle to the students, showing their accomplishment. This adds motivation and allows to check the progression and get feedback on “blind” spots (Gibbs 2010).

Since the robotic design project itself is quite challenging and time-consuming as well as imposing high requirements with regards to self-organization, communication and collaboration, motivation is a key factor for the success of the student teams. Therefore, different levels of motivation are implemented, the most obvious ones being a design price for the most innovative robot and a price for winning the final robot contest. Both prices are endowed and officially handed over to the winning teams by a local Foundation for the Westphalian University, reinstating the importance for the students.

Apart from this, it is highly recommended that the course design itself meets the Constructive Alignment of Biggs (see figure 1). This will result in high overall motivation and a clearer understanding of each activity (Biggs 2003). The paradigm of the Constructive Alignment states that the learning outcomes should be aligned to the teaching activities and the assessment, i.e. exams.

*Figure 1. Constructive Alignment for the selected teaching approach (accord. to Biggs 1999).*



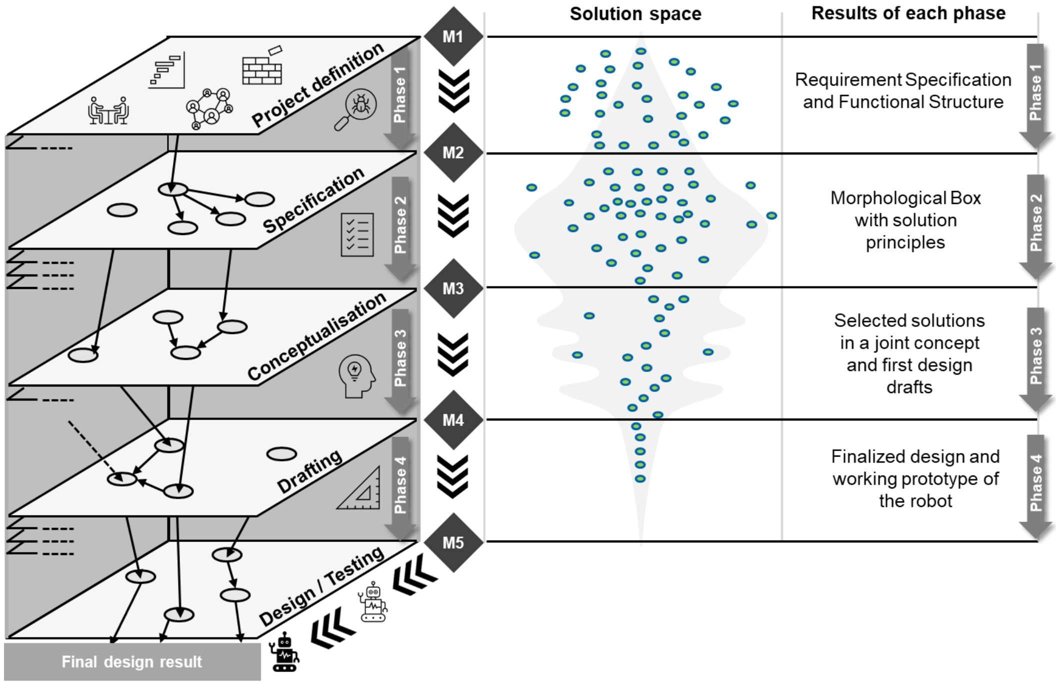

In this presented teaching approach, each teaching method (e.g. theoretical lecture or practical session) is directly linked to a corresponding learning outcome (skill needed for the completion of the design challenge). The learning outcomes are individually tested by Moodle quizzes as well as team-wise by the turned-in design challenges. This is coupled with almost direct feedback on the quizzes and tasks, so that students can improve on potential weaknesses. Furthermore, the final written exam of the course builds on the exact same learning outcomes that the students achieved during the robot design project, increasing the motivation to finish this project in time.

## 3. Overview of the methodical development process

In order to organize the overall development process and reproduce industrial standards, the German VDI guideline 2221 (VDI 1993) is applied (see figure 2). It provides 4 basic phases, which the students must pass during the design project: specification (1), conceptualization (2), draft (3), design/testing (4). In the first phase, the given task of developing a remote-controlled robot is examined and further requirements are specified. This results in detailed specifications and a first functional description for the robot. The second phase of conceptualization entails a thorough search for physical solutions, i.e. active principles, to solve the abstract functions of the product (Lindemann, 2009). The solution space is enlarged during this phase in order to find a large number of possible solutions. Since the final design of the product is still undetermined, it makes sense to generate a high number of potential solutions, in case one of the selected principles fails (Pahl et. al., 2007). All identified principles are gathered in a Morphological Box, which lists the product functions together with the possible solutions. The third phase starts with selecting principles from the Morphological Box and joining them into three different concepts for each team, which are then evaluated by constructing them with a mechanical LEGO set. The best concept then gets selected for further detailing.

p-ISSN: 2184-044X e-ISSN: 2184-1489 ISBN: 978-989-35106-4-3 © 2023

*Figure 2. Methodical design approach and phases of the student project (inspired by Jansen, 2007).*




The project concludes with the fourth phase by realizing each selected concept as a real prototype. The students use CAD software to design the robot with its components and rapid manufacturing in form of 3D printing to realize the prototype. At the end of the course, each robot enters the final contest as a form of a design evaluation. Each phase is time boxed and provides a milestone (M1-M5), at which the students must turn in their results for grading.

### 3.1. Learning activities during planning (1) and conceptualisation (2)

The main target of the first phase is to generate a complete set of specifications for the design of the robot. To mimic the real-world experience, the students had to interview a customer (role-played by a university employee). Customer requirements included the description of the fragile load, timeframe, max cost, weight, build space, inspection intervals, available assembly tools and time as well as typical terrain. These requirements had to be specified with quantitative values to allow for testing in phase 4.

In order to finish the first phase, the students also had to find technical functions which realized the identified requirements, e.g. supply energy, carry load, defend load, move robot forward, steer robot, attack robot. This step helped to focus on the functions without jumping directly to solution ideas. All functions can be interconnected by different flows (i.e. material, energy, signal), thus representing an early design architecture of the robot.

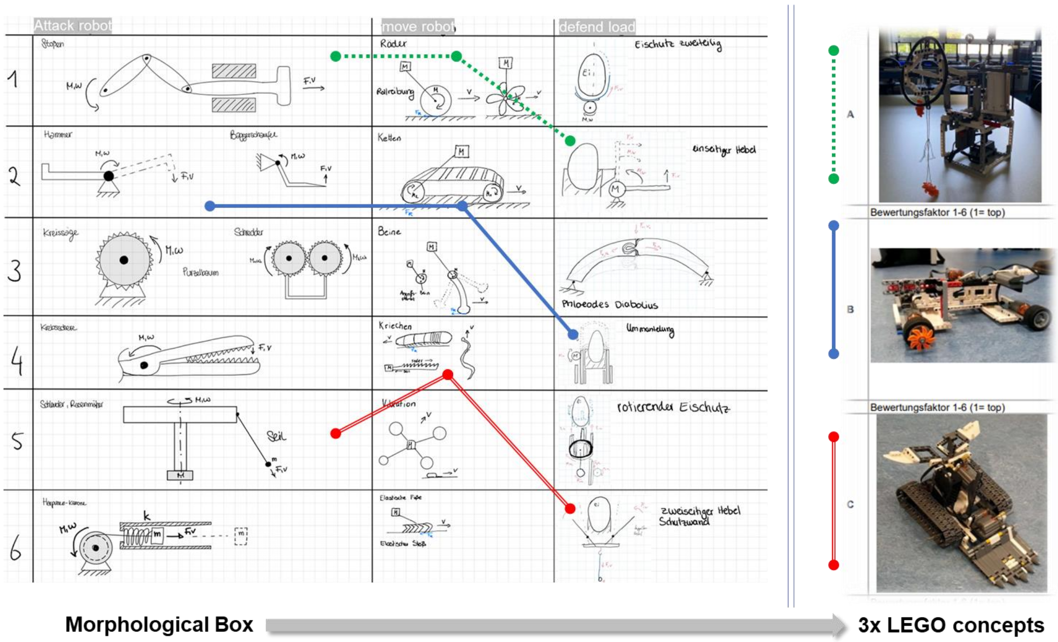
Starting with the second phase, the students needed to find physical means of realization for each of the included technical functions. Different forms of support were given to the students to use, e.g. a physical effect catalogue, mechanical design catalogues for common functions or analogy searches in the field of biology. Figure 3 represents the Morphological Box of one student team, which includes three functions: move robot, defend load and attack robot. For each function, six solution ideas had to be found, with at least one solution based on a biological analogy. Before continuing, three concepts had to be marked and realized as a small prototypes to evaluate their feasibility (see figure 3). The feasibility study was approached from two directions.

Firstly, each team had to build their concepts with LEGO construction kits that included remote controlled motors during in a 90 minutes design challenge. This massively helped the students to manifest the abstract idea of the concepts and to form a viable opinion about the prospects for each concept. Necessary design work was divided by the team members.

Secondly, each concept was systematically assessed via fixed criteria including speed, grip, stability, reliability, force, frequency, range and protection effectiveness. At the end of this phase, one concept had to be chosen within each team. The methodical assessment helped to limit friction within the teams and provided a common for the next phase.

At the end of each phase, the students had to turn in their results, which were graded teamwise: specifications and functional architecture (M2), Morphological Box, LEGO concepts, final concept (M3).

*Figure 3. Morphological Box for physical solutions and realised LEGO concepts (phase 2).*



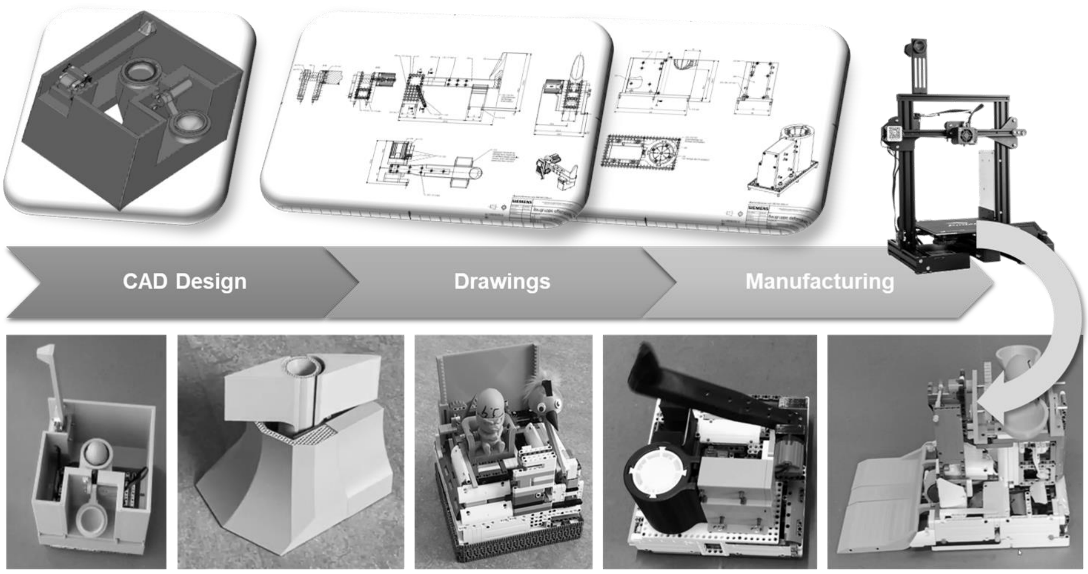

## 3.2. Learning activities during design, implementation (3) and testing (4)

The highest ranked concept then had to be designed using CAD software and should be realized as a 3D printed prototype using FDM (fused deposition modelling with PLA). The chassis of the robot had to be built out of the construction kit, while the remote-controlled motors could be used for moving, defending and attacking. The defend/attack functions had to be fully designed in a sub-assembly without the use of metal parts and should only entail self-designed printed parts. For each sub-assembly, technical drawings were expected and graded at M4.

The prototypes had to be fully functional and tested against their specifications before they were allowed to enter the final contest (see figure 4). This was implemented by having each team uploading a video of the working prototype at M5, showing every function of the robot. Students could come up with creative solutions as on how to present their results, resulting in impressive “cinematic” videos including overlays, background music and professional voice overs using veed.io, which shows their motivation.

Finally, after passing a mandatory safety test, each robot was successfully entered into the 1on1 contest, where the goal was to protect the own fragile load while attacking the other robot in fixed arena of 3m x 3m. The tournament ended with a clear winner and the design price as well as the tournament price was handed over to the different student teams.

*Figure 4. CAD designs and final 3D printed prototypes (phase 3 and 4).*



## 4. Critical review of the teaching approach and outlook

The overall goal of teaching mechatronic system design under real-world conditions was achieved during this course, judging by the quality of the final outcomes of the teams in terms of functional robots and the successful competitive contest at the end. Each robot was able to perform all predefined actions as specified and all teams completed the design project on time and within their budget. They overcame numerous challenges that also exist in industrial projects, i.e. non-working components, electrical problems, part shortages, mechanical fractures during testing or failed 3D prints.

According to Jara & Mellar 2010, student feedback is one the most important parameters for course improvement. Therefore, this course was thoroughly evaluated by the students via anonymous forms. Regarding this feedback, the robotic project was very positively mentioned due to the possibility of applying theoretical knowledge directly to a practical project. Further positive remarks include the chance for teamwork, the quizzes with badges and a high motivation due to the real-world design process. The final competitive 1vs1 contest also added motivation. Some students also mentioned that the milestones with predefined deadlines helped them to stay engaged and not to lose focus.

Critical remarks by the students included the very high effort for the team project with regards to the composition of the final grade (1/3 project + 2/3 written exam). As a solution, it was proposed that the project presentation or the contest could replace the final exam. In addition, more time was requested for the final CAD design of the prototypes, especially compared to first the phases of the project (time-distribution was roughly equal for phases 1-2 and 3-4). Another remark was the high overall workload for the students due to other projects in their current semester. This is a point that clearly needs to be addressed and checked when planning such a practical project.

Overall, it can be summarized that the game-based teaching approach was very successful. During the students’ collaboration, not one team had problems with the team dynamics, which might be attributed in part to the clear setup with milestones and quick feedback rounds. The online quizzes help the students to test their theoretical knowledge. The continuous grading of the results each team turned in at the various milestones ensured constant feedback on their performance.

Most notably, the added value of the practical design project was immense. This was highly reflected in the motivation of the students to work far more in order to become the winning team in the final contest, showing their competitive nature and again highlighting the importance of the Constructive Alignment (Biggs 2014). In the next instance of this course, the students’ feedback will be incorporated. The composition of the grades will be adjusted to 50/50 and the draft and design phase will receive a large timeframe, while the graded online quizzes and the design challenges will be continued. Furthermore, it is planned to conduct empirical research in form of a descriptive study (Blessing et. al. 2009) regarding the effectiveness of this teaching approach.

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