How to boost the students’ interest to engineering graphics?

M Dobelis¹, M Sroka-Bizon², and T Branoff³

¹ Faculty of Civil Engineering, Riga Technical University, Kipsalas St. 6A, Riga, LV-1048, Latvia
² Faculty of Civil Engineering, Silesian University of Technology, Krzywoustego St 7, 44-100, Gliwice, Poland
³ Department of Technology, Illinois State University, 215E Turner Hall, Campus Box 5100, Normal, IL, 61790-5100, USA

E-mail: Modris.Dobelis@rtu.lv

Abstract. Evident boost in Architecture, Engineering and Construction (AEC) industry now is possible using BIM concept – Building Information Modelling. A similar workflow under term Product Lifecycle Management (PLM) is known for quite a time. Successful introduction of these technologies require extensive application of 3D geometric models. Development of spatial imagination and 3D models by means of CAD systems should be tackled in the engineering courses. Universities have to participate more actively in the process of faster implementation of these technologies into life. A common background knowledge required to handle this problem is a development of spatial visualization skills since in the backbone of the both these concepts there is a three-dimensional (3D) geometric model or database. The former classic university courses like descriptive geometry and engineering graphics used in the last century have undergone considerable reduction in credit points, sometimes caused by administrative orders or experienced decent content changes dictated by IT achievements. However, development of the spatial comprehension and visualization skills should not be under estimated in the future syllabuses, because they are crucial for 3D modelling in a wide range of engineering applications. The paper will share an experience about recent research about teaching spatial comprehension, 3D visualization and CAD communication skills in technical universities. Results of the experience gained from a 2011 Fulbright Scholarship teaching and research project about the measuring the engineering graphics literacy skills and further application in practice are represented as well. The paper will focus on a review of adopted and tested teaching methods and approaches rather than detailed analysis of the situation in general.

1. Introduction

A fundamental engineering graphics education in a curricula should be acknowledged based on its role in a modern project evolution. Nowadays any project development involves several stages, such as conceptual design, detailing, analysis, iterative re-design, manufacturing, assembling, testing, management, etc. Both in a typical engineering product development and building industry scenarios most stages are performed with Computer Aided Design (CAD) systems. Vast amount of new Information Technology (IT) tools and media appear every year with increasing speed. However, the links between individual stages of CAD design processes very often are scheduled manually. Evident boost in Architecture, Engineering and Construction (AEC) industry now is possible using BIM concept – Building Information Modelling [1]. For the design of industrial and consumer products, a similar workflow under term of Product Lifecycle Management (PLM) is known for quite a time [2]. Recent
studies show that fundamental PLM functionalities can create a synergy with the BIM-enabled AEC industry [3]. Successful introduction of these technologies starting from the early stages of the project development require extensive application of 3D geometric models. Questions about the development of spatial imagination and creation of 3D models by means of CAD systems should be included in the courses of engineering graphics.

There are significant challenges for these technologies and software tools and how to bring them into service as fast as possible to replace the traditional use of CAD applications in a wide range of companies. Universities also have to participate more actively in the process of faster implementation of these technologies into life. A common background knowledge required to tackle this problem is a development of spatial visualization skills since in the backbone of the both these concepts there is a three-dimensional (3D) geometric model or database. The former classic university courses like descriptive geometry and engineering graphics used in the last century have undergone considerable reduction in credit points, sometimes caused by administrative orders or experienced decent content changes dictated by IT achievements. However, development of the spatial comprehension and visualization skills should not be under estimated in the future syllabuses, because they are crucial for 3D modelling in a wide range of engineering applications.

2. Blended Learning

New hardware and digital tools introduced by technological developments have significantly changed the education methods, teaching process, its access and use, and availability of present information. Rapid development of information technologies have stimulated researches in the field of education and educational technologies since the methods of the 21st century are technology-oriented methods.

Over the last decade the students’ attitudes and behaviors have changed drastically with changes in ways of studying and communicating. A completely new generation of young people, which grew up in an era of high-speed internet and numerous advanced technological gadgets, are enrolling the universities already for several years. Many university students come with a setup "Why should I study this because I do not need this now?" forgetting about gaining practical marketable skills that will help them now and later. It is extremely difficult to hold their interest on subject matter in engineering classes, which require much attention.

A current staff from the Baby Boomer, X, and Millennial generations face problems of controlling the study process in new environment and convey the experience to a new Generation Z. It does not work in a way it did just a decade ago, when verbal face-to-face or written communication was a standard. Messaging apps that "don't leave a paper trail," where communications are sent and quickly gone, are not the best methods to gain practical skills in what industry expects from graduates. Recent research shows that much effort is spent in many teaching areas on how to trigger the Generation Z’s interest in studies and how to enhance students’ readiness, expectancy, acceptance, self-regulation, collaboration, problem solving, and joy of learning [4]. It is beyond a doubt that the use of IT in education can support student-centered and collaborative learning and develop thinking skills and creativity, but they have to be used in a reasonable balance. Contemporary research shows that triggering interest can enhance students’ spatial imagination skills, creativity, joy of learning, improved everyday performance and the outcome [4].

AR applications enable faster comprehension of complex spatial problems and relationships, which makes them useful during the learning process in engineering graphic courses. An AR didactic toolkit AR-DEHAES [5] was successfully adopted to promote a student-centered learning in engineering graphics courses [6]. This entertaining IT tool is based on the application of AR and requires a computer, webcam, and specially designed set of materials for learning. The main purpose of fostering an interest in acquiring spatial comprehension with modern IT tools was achieved. About 81% of the respondents admitted that working with AR-DEHAES allows perceiving and visualizing spatial objects much easier.

Blended learning might be one of the solutions, which refers to a course of study in which the teacher in the traditional classroom delivers parts of some topics, while the learner independently of the teacher, preferably on-line, undertakes other parts. Blended learning will work out only if a creative atmosphere
may be set up for practice in an exciting and stimulating way. Five areas of possible change are identified that deserve attention and can be integrated into the classroom without a complete revamp of the curriculum [7]. They are as follows: integrate active and problem based learning (1); help students extract answers from an ocean of information (2); assess often and provide feedback (3); engage creativity (4), and help students make connections (5).

Diverse knowledge background of the students enrolling into engineering programs leads to assorted experiences and expectations in terms of problems of teaching and learning with and without engineering graphics basics from the high school. The diversity of the enrolling students will remain in the future in terms of prior practical experiences and it demands innovative methods that would help to decrease the high dropout rate and promote effective learning.

3. Pencil Aided Drafting or Computer Aided Design?
Spatial reasoning skills strongly correlate to the mathematical abilities and to the success in many technical fields, which require the application of CAD software in industry. This suggests that parents and schools should pay more attention to the pupils’ creative skills development while playing with such everyday items as Legos, construction toys, or even video games that require visualization and mental rotation skills. Educational computer games can be developed for training spatial imagination in specific aspects of engineering graphics, however it appears to be studied just occasionally [8]. In general, spatial reasoning skills are frequently associated with higher levels of academic achievement and creativity where the content creation requires it. These skills are measured with the ability to visualize and manipulate 2D and 3D objects, and are considered as being related directly to the achievements in technology, engineering, math, and science [9]. However, recently reported results prove that spatial reasoning skills are often not identified as areas of aptitude in children and as a result, they may not be taught, valued, or assessed in an academic setting.

A review [10] about the changes in engineering graphics education, dictated by IT advancements, proposes a set of student learning outcomes in teaching communication graphics for the next generation of globally competitive engineers. Results of the survey conducted in 2004 and 2012 among 24 faculty indicate that new computer graphics tools and techniques are now preferred and well accepted mode of graphical communication in engineering education in USA. The summarized in the table 1 results of the research show the identified before outcomes in engineering graphics and the changes in their impact from the point of view of the faculty. These results indicate that long-standing techniques of descriptive geometry and manual geometric construction were no longer well recognized outcomes with respect to the computer aided methods. However, some of the traditional geometry problem solving skills and ability to use hand drawing tools in 2012 have been re-appreciated in comparison to 2004.

Results of the students’ self-assessment survey [10] indicated that significant gain in all outcomes can be achieved in a graphics course, albeit in a self-reported manner. The conclusions drawn from this research state that modern engineering graphics education should be considered an important form of engineering communication, and should focus on three main areas of instruction. This instruction should include engineering graphics fundamentals (1), computer graphics modelling (2), and computer model applications to digital analysis, manufacturing, and design projects (3). The expected outcomes are in well agreement with the ABET (Accreditation Board for Engineering and Technology) criterion calling for “effective communication” in contemporary engineering education. Specifically, 3D computer modelling, assembly modelling, and digital model application to design and manufacturing all received significant notices in the survey results [10].

The experience of several schools worldwide proves that the most effective way is if this field uses a contemporary approach of teaching the traditional and essential engineering graphics skills by integrating them with 3D CAD modelling content. A fundamental textbook [11] is adopted in many leading universities not only in the USA, but also worldwide, and perfectly covers the basic visualization and sketching techniques that enable students to create and communicate graphic ideas effectively.
Table 1. The Summary Results from a Graphics Faculty Outcomes Survey (N=24) [10]. Importance of the outcomes are listed from highest to lowest ranking (Scale 5) in 2012.

| No. of outcome                                                                 | The identified from the literature review of the outcomes engineering graphics | Rank in 2004 | Rank in 2012 | Changes |
|--------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-------------|-------------|---------|
| 1. Ability to Create 3D Solid Computer Models                                   |                                                                                | 4.75        | 4.75        | -       |
| 2. Ability to Sketch Engineering Objects in the Freehand Mode                   |                                                                                | 4.67        | 4.54        | ↓       |
| 3. Ability to Visualize 3D Solid Computer Models                               |                                                                                | 4.46        | 4.54        | ↑       |
| 4. Ability to Create 3D Assemblies of Computer Models                          |                                                                                | 4.29        | 4.54        | ↑       |
| 5. Ability to Create Dimensions                                                |                                                                                | 4.38        | 4.38        | -       |
| 6. Ability to Create Section Views                                             |                                                                                | 4.13        | 4.33        | ↑       |
| 7. Ability to Generate Engineering Drawings from Computer Models               |                                                                                | 4.33        | 4.29        | ↓       |
| 8. Ability to Analyse 3D Computer Models                                       |                                                                                | 3.71        | 4.13        | ↑       |
| 9. Ability to Create 2D Computer Geometry                                      |                                                                                | 4.21        | 4.08        | ↓       |
| 10. Ability to Perform Design Projects                                         |                                                                                | 3.96        | 4.08        | ↑       |
| 11. Knowledge of Manufacturing and Rapid Prototyping Methods                    |                                                                                | 3.42        | 3.63        | ↑       |
| 12. Ability to Create Presentation Graphics                                     |                                                                                | 3.42        | 3.46        | ↑       |
| 13. Ability to Solve Traditional Descriptive Geometry Problems                 |                                                                                | 2.29        | 2.75        | ↑       |
| 14. Ability to Create Geometric Construction with Hand Tools                    |                                                                                | 2.13        | 2.71        | ↑       |

4. Contemporary Communication Graphics
A 3 ECTS course BTG701 "Basics of Communication Graphics" was designed particularly for the program “Intellectual Robotic Systems” at RTU in a response to the program holders' wish to include a conventional engineering graphics course to acquaint the students with the basics of engineering design. The course is based on an approach used at the North Carolina State University (NCSU) in a similar course GC350 "Applied CAD and Geometric Controls", which was observed in details during the exchange of experience in spring 2011 Fulbright Scholarship teaching and research project.

One half of the course deals with the basic concepts of descriptive geometry and engineering graphics using conventional pencil technique. The second part covers the creation of 3D parts, virtual assembly of components and documentation using parametric feature based modelling software SolidWorks. However, this part is merged with classic pencil technique from the third week and the same home assignments are required to be completed in both techniques to have a computer solution for assistance. Midterm exam is concluded in a pencil technique without CAD assistance and includes the sectioning of simple geometric primitives with plane and representing them in multi-view drawing. The second part is focused on 3D model creation from different type of information: from a pictorial view with given dimensions, from a multi-view drawing when a form and size of the geometric primitives has to be analysed and determined, and from assembly drawing with bill of materials and only installation and overall dimensions given. An assembly drawing with 6-8 parts in a semester project masters the skills of "reading", and proves the understanding by "writing" in the form of 3D models.

As the privilege of this method is a possibility for the students to see the result in 3D and check it much faster, especially if the teacher has prepared an automated assessment. If the same task is assigned to all students, concerns of plagiarism prevention issue still remain. A preparation of numerous variants of individual tasks in a session is a common practice for conventional engineering graphics courses.

A drawback of the use of the classic pencil technique while mastering engineering drawing "reading and writing" literacy skills is poor hand drafting practices, which cannot be mastered in short courses.
A lack of students' patience in combining an imaginary spatial image of an object while navigating through the "forest of lines" in the corresponding multi-view drawing is another hard to beat factor. It often causes when the students try to dimension parts in the drawings but do it in a chaotic way between neighbouring lines without any spatial reasoning. A requirement to create a feature based model forces to analyse the 3D geometry with caution, determine the proper size and location of geometric primitives, and reproduce them in a valid virtual model. Requirement to use fully defined sketches allows the students to self-assess each modelling step promptly.

The developed course is in use since fall 2013 and later was successfully acknowledged by another study program "Adaptronics". It is interesting to mention, that lately a program "Automobile Transport" requested to design a new course "Mechanical Engineering Drafting" which includes practicing the drawing of advanced machine elements using pencil aided technique. Just a couple of informative overall AutoCAD demonstration classes were requested with the suggestion that the students might want to practice it by themselves from a numerous available tutorials including video tutorials in a native language, if it is needed. Similar manual engineering graphics and drafting courses were is use in a majority of technical universities worldwide just two or three decades ago, but them they were restructure at a different speed depending on the on the countries' IT welfare and universities' hardware capacity. Classic manual drafting courses were gradually abolished in favour to emerging courses dealing with general computer skills, like word processing, spreadsheet calculation and in rare cases some programming in languages, like Pascal etc.

5. Measuring Engineering Graphics Literacy

Engineering graphics educators have been studying students’ modelling strategies and methods of evaluating models for approximately twenty years. Recently conducted studies tried to identify how the understanding of engineering graphics literacy correlates with interpreting an assembly drawing, visualizing the various parts, and then modelling these parts within a constraint-based modelling software. These studies revealed that the modelling test used was related to other measures of student success in courses – spatial visualization ability, score on the final project, and score on the final exam.

An attempt to measure an engineering graphics literacy was made in a Fulbright Scholarship teaching and research project in spring 2011 at NCSU [12]. It was supposed that by means of advanced “technologic toy” – a contemporary 3D parametric modelling CAD software – is possible to engage the students into entertaining experiment. The students were required to prove their spatial comprehension and the skills of the interpretation of the assembly drawing by modelling in a limited period as many individual parts as possible.

Several devices consisting from 6-10 parts with different levels of complexity were selected and modeled to check the model validity. Typical elements of machine parts like threads, chamfers, fillets, notches, grooves, springs, etc. were present in these parts. Multi-view assembly drawings with parts list were printed and used for practical training and pilot test studies. This approach insured that the assembly drawings prepared this way will be most suitable for “reading and writing” test and they could not be misinterpreted easily for being not clear enough.

Educators from several universities worldwide were addressed and suggested to perform this “reading and writing” test using parametric feature based modeling software like SolidWorks, SolidEdge, Inventor, etc. [12]. Alternatively they could organize the test in a modified way even with 2D drafting software and submitting their rules and final results for comparison. A positive response was received from two universities in Latvia, one in Croatia, and one in Russian Federation and they joined the research to test the suggested methodology conducted from NCSU. The staff from these universities received the set of drawings for training and actual test. The suggested quantitative evaluation method of “reading and writing” test combined with 3D parametric modeling could be used for accurate measuring of graphic literacy level of the engineering students. One of the main drawbacks is a concern about the ability to scale-up the project to handle more students because the time required assessing the student files is very high.
6. Reverse Engineering Projects

Many engineering graphics educational programs use some form of project activities in combination with teaching the graphics theory, to inspire the students with hands-on applications, e.g. Reverse Engineering (RE) project. RE project is a systematic methodology for analysing the design of an existing device or system. The project consists of student teams selecting and reverse engineering a mechanical device through a dissection and documentation process [10]. This concept has been used in a 4.5 ECTS free choice course BTG450 at RTU. The course starts with an overview of PLM concept in mechanical engineering. An analysis of the geometry of typical machine parts is covered and a practical training is performed in a context with parametric feature based design using SolidWorks. Parametric sketches, constraints and their use are discussed in hands-on training examples covering the most widely used basic modelling features like Extrude, Revolve, Loft, and Sweep. Advanced topics like design library, Toolbox, hole wizard, threads, etc. are included in much faster pace. Assembly modelling and document production in a Drawing mode with the creation of views, sections, aligned and crop views, dimensioning, and creation of Bill of Materials concludes the practical training. Home works are assigned as a rule to master practical skills. The checking of individual home works requires extensive faculty work on opening each file and is very time-consuming. Although the students are warned to submit their own work, rare cases of plagiarism warn about aspects, which have to be kept in mind.

In an attempt to search for automation of the checking process, an existing SolidWorks Add-In GraderWorks v.2.37 [13] was tested on the compulsory home works. Using this tool it is easy to catch the plagiarism, but rather difficult to assess the obtained result against the expected or the correct answer using the provided options for automatic checking of the mass properties of model and metadata from files. Current version of GraderWorks allows to design a custom rubric of items to be analyzed in students' files and even check if each sketch is fully defined. However, the students have so many different and diverse cognitive approaches that it is not possible to identify the only one supposedly correct track of the solution, which can be easily checked with the tool. No other mention of the use of this tool for similar purposes was find in the literature.

The BTG450 course is concluded with a RE project. Generally, the projects are organized as a teamwork [10], but in the particular course at RTU the students choose individual projects. A mechanical device consisting from 7-10 parts, has to be disassembled, analyzed and the parts measured the parts, and afterwards 3D models created and assembled. Some students get so excited to create projects with even more than 100 components, while some others hardly meet the minimum requirements. Final grade takes into account both the individual semester performance and project presentation results. It is quite difficult to compare and assess the diverse and complex projects quantitatively; therefore, when in spring 2018 a considerably increased number of students selected the course it was decided to choose an alternative method of assessment and motivation – a certification.

7. Certification as a Motivator

Over the last decade, leading CAD software developers have designed and launched certification exams for many products. A Dassault Systèmes company developed Certified SolidWorks Associate – Academic (CSWA – Academic) certification program, which is intended for a student with a minimum of six to nine months of SolidWorks experience and basic knowledge of engineering and fundamentals and practices. Worldwide interest in the certification is constantly increasing over ten years [14].

To boost the students’ interest, a “motivating carrot” in the form of CSWA – Academic exam was suggested as an alternative to the RE project and a course exam. A challenge to receive an internationally recognized certificate with personal listing on the CSWA Academic directory triggered a positive attitude from all students, and the students chose this suggested option instead of RE project. In order to cover all the topics required for certification a slightly modified course included wider range of topics, which was not possible in the previous course because of limited absorbing capacity resulting from insufficient interest. In addition to this much faster training pace was expected – all training had to be completed in one study semester or four months instead of six month claimed by certification experts.
Some training exercises used before in the course for practice and home works were modified and put on Moodle for automated checking to mimic the actual certification tests as close as possible.

This “carrot motivating” approach was tested on 65 students from “Medical Engineering and Physics” program at RTU in the course BTG450 by a lecturer in a class with 30 workstations in two sessions. There were 33 first year students, 24 second year and 8 fourth year students, but no gender differences will be analysed in this paper. They all had taken a compulsory course BTG131 “Descriptive Geometry and Engineering Graphics” in the very first semester on the studies. Inspired by the students’ interest and a wish to facilitate reaching their goal, the teacher dubbed his on-site class hands-on tutorials with separately recorded and edited video tutorials for part and assembly modelling exercises. After several weeks, the number of students in the class slightly decreased. An answer to the question "Why this is happening?" was "We can do it at home when we want!" This proved to be a wrong assumption because at home there were always too many distractions. This was an unexpected feedback from the experiment, which raises doubts about the usefulness of such an approach in the future.

To earn free CSWA exam vouchers a free sample exam had to be completed with at least 90 points. CSWA – Academic exam version in two parts with 90 min each was preferred to a single three-hour version based on the previous observations that some students are having difficulties to stay focused for long time. To get a certificate both parts of the exam had to be completed with at least 80 points each from a maximum 120 possible. The CSWA certification outcome summarized in the table 2 shows that 29 students or 44.6% succeeded. To achieve this result only three of the 2nd year students had to retake only one part of the real exam. For about one quarter of the first and second year students the pace seemed to be a little too high, so they did not make any attempt to qualify for the certification and switched to a slow track "stick mode" with the same compulsory home assignments. To get the maximum grade in the course, which is equal to those with the CSWA certificate, they had to prepare and defend the RE project. The results were administered in a spreadsheet with single formula where the number of completed home works and all points earned in the three parts of the certification were also taken into account to ensure a quantitative and fair assessment. Much lower but still passing grade was possible to receive without RE project provided some CSWA credits were earned as well. Measurable elements of the performance used in the assessment and strict rules announced in the beginning of the course allowed to avoid a possible complains about the grading.

| Year of Study | No. of Students | Sample Exam Attempts | % of Attempts | Passed Sample Exam | Repeated Sample Exam | Average Points in Sample Exam | Passed CSWA Exam | Retake one part of CSWA | Average Points in CSWA Exam | Made RE Project | % from all | Quit the course |
|---------------|-----------------|----------------------|---------------|--------------------|----------------------|-------------------------------|-----------------|------------------------|---------------------------|----------------|-----------|----------------|
| 1st           | 33              | 26                   | 78.8          | 20                 | 4                    | 105                          | 12              | 0                      | 212                       | 7              | 36.4      | 1              |
| 2nd           | 24              | 18                   | 75.0          | 16                 | 0                    | 107                          | 12              | 3                      | 219                       | 9              | 50.0      | 1              |
| 4th           | 8               | 8                    | 100.0         | 8                  | 0                    | 129                          | 5               | 0                      | 214                       | 0              | 62.5      | 0              |
| Total         | 65              | 52                   | 84.6          | 44                 | 4                    | 114                          | 29              | 3                      | 215                       | 16             | 49.6      | 2              |
|               | 100.0%          | 80.0%                | 67.7%         | 6.2%               | 87.7%                | 44.6%                        | 4.6%            | 89.6%                  | 24.6%                     | 3.1%           |           |                |

The distribution of the number of CSWA certificate holders with increasing a study year quite well characterizes a constantly ascending positive attitude to the self-sufficient learning. About one third (36.4%) of the 1st year students, one half of 2nd year and almost two thirds (62.5%) of 4th year students passed the certification exam with a score close to the average 215 points (89.6%) out of 240 possible.

8. The Role of Competitions
To contribute an interest in comprehension of engineering drawings beyond academic courses in more challenging activities, competitions were organized for well-motivated students who want to prove their
knowledge. The annual Olympic CAD & PAD contests were organized in two tracks – CAD and PAD – Pencil Aided Design. The type of tasks varied from year to year and was always different for each track, but never exceeded two astronomic hours.

A typical task for the CAD track was to check the students ability to “read and write” or interpret an assembly drawing of some mechanical device consisting from 6-11 components. SolidWorks was used as a “writing” tool to prove their understanding to prepare exact models of the components, the form and size of which had to be determined from the assembly drawing. No pictorial representation was given but after the contest the students were acquainted with the real part they modelled just a while ago and they could instantly assess what they missed interpreting the multi-view drawing. Figure 1 renders an idea about the complexity of the part to be modelled – how many and what kind of views and section views were given in the contest in fall 2015.

Figure 1. A complexity of a part used in an Olympic CAD contest in fall 2015.

Certificates acknowledging participation in the contest and small prizes for the best was only a minor motivator. Several students reported the participation as self-motivated challenge to test their skills in what they thought might be closely related with their future career. Graphic competitions were terminated after ten years of activities in 2015 the as the organizers from student side switched to other type of competitions, like the design of wafer towers, the construction of paper or pasta bridges, etc.

9. Conclusions
The mode of instruction in the areas of engineering and technology has changed. The traditional lecture setting where the teacher is the primary deliverer of information is no longer the preferred method of instruction. The students have to take more responsibility for their own learning using IT to gather relevant information at unprecedented pace and quality, which was not available before.
With wide access to the information and educational opportunities that IT has enabled, the teacher’s role can be shifted to be a “Guide on the Side” if one can find motivating tools. Inclusion of professional certification of the skills and organizing rewarding contests in the courses are just a few of these tools.

Many schools and universities across the world are constantly redesigning learning spaces to enable new models of education, foster more interaction and small group work, and the use of IT as cognitive facilitator. Technologies like video tutorials, Augmented Reality (AR) applications, instant automated checking of home works and gaming setup are used for training spatial comprehension and developing practical skills in engineering education.

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