



Application of Computer Simulation and Animation (CSA) in Teaching and Learning Engineering Mechanics

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Abstract

Use of computer simulation and animation (CSA) in higher education is growing rapidly and has become a major trend in undergraduate engineering education. This paper conducts a comprehensive and critical literature review regarding the use of CSA as a learning aid to teach engineering mechanics courses. The paper addresses two main topics: (1) pedagogical innovations in the instruction of engineering mechanics, and (2) using CSA as a learning tool in engineering mechanics education. Representative pedagogical innovations are clustered into three categories: (1) altering the engineering mechanics curriculum, (2) active learning strategies, and (3) the application of enhancement resources. Focusing on CSA as an effective enhancement tool, this literature review summarizes the main characteristics of CSA modules that impact student learning: visualization enhancement, interactive features, and straightforwardness. Major theoretical, methodological issues and practical implications as well as the strengths and weaknesses in the published studies within cognitive learning domain are reviewed. The literature review shows that although all studies justify the practical effectiveness of CSA modules in improving learning styles, few of them are explicitly associated with a “learning theory” model. The most important advantages of CSA modules cited in the literature are: interactive feature, fostering students’ visualization, and enhancing their problem-solving process. It is suggested in this paper that CSA modules cannot be considered as a stand-alone pedagogical resource since they cannot replace conventional classroom instruction.

Introduction

In most engineering programs, engineering mechanics includes statics, dynamics, and strength of materials, which are required courses in mechanical, civil, environmental, and biological engineering programs^{1, 2, 3}. The complexity and diversity of problems and concepts make engineering mechanics a challenge for many students^{4, 5, 6}. However, these are not the only reasons that motivate instructors to create new tools and methods. Even though the difficulty of representations exists in many engineering drawing and design courses, its combination with complex mathematical and conceptual analysis in mechanics problems makes it extremely difficult for students to learn⁷. Instructors in engineering mechanics always try to represent 2D and 3D motion through static diagrams and explanations. To date, numerous educational tools and methods have been developed by various researchers to improve student performance in engineering mechanics^{6, 7, 8}. These methods include, among others, novel teaching techniques, instructive and interactive computer modules, and the involvement of students in the process of learning through a variety of projects and similar activities^{9, 10}.

Most of the above-mentioned tools/methods attempt either to distribute the content in order to decrease the cognitive load, or to enhance the representation of the content that is meant to assist students with the geometrical and physical perceptions^{2, 5}. Notable advancements in the creation of computer simulation and animation (CSA) in recent years have drawn great attention and placed CSA on the top of the educational enhancement tools list¹³. Nevertheless, in most current

research studies, emphasis is on the technical characteristics of CSA modules, rather than on rigorous assessments of their impacts on students' learning^{8, 14}. In reporting students' experiences with CSA modules, results most often include the frequency of positive feedback made by students. Limited research studies involve rigorous assessments of the effects of CSA modules on students' learning and problem solving^{15, 16}.

It has become a widespread practice to use computer-based tools to enhance learning. However, using computers just for the sake of using computers or to appear "modern" can be a disadvantage to teaching engineering mechanics. In spite of significant progress in computer-assisted teaching, most students need to draw free-body diagrams and then write equilibrium equations, kinematic constraints, etc., to grasp different concepts of engineering mechanics. For this reason, the most successful methods, such as computer-aided instruction problems and interactive computer tutorials, are an augmentation of the traditional context^{7, 17}. In science education, most research studies demonstrate that computer tools improve learning through simulation, better representation, fostering student involvement, and decreasing the instructor's load¹⁸. Use of CSA in higher education is rapidly increasing and has become a major trend in undergraduate engineering education^{18, 19}. This trend explains the substantive amount of literature concerning the research and development of novel tools and methods for teaching engineering mechanics.

This paper provides a comprehensive and critical literature review on two major themes: (1) pedagogical innovations in the instruction of engineering mechanics, and (2) using CSA as a learning tool in engineering mechanics education. These two themes converge to give new insights concerning different aspects of CSA's in engineering mechanics education as well as answering the following questions:

- What characteristics of CSA make it a favorite choice for improving engineering mechanics pedagogy?
- What aspects of cognitive domains are targeted by a CSA module?
- By what means is the pedagogical effectiveness of CSA modules evaluated?

A brief scrutiny of the literature shows that a substantial volume of research exists concerning the use of computers in education ranging from K-12 to post-secondary education. The same situation exists in many fields of post-secondary education. This review has been limited to those published studies focusing on engineering mechanics or closely related subjects. A number of references have been cited for theoretical or basic research works^{20, 21}. Major characteristics, implications, focused topics, and issues associated with the above mentioned questions are categorized and presented in tabular format in subsequent analysis sections.

Defining computer simulation and animation (CSA)

Despite the fact that "computer simulation and animation" as a term is widely used in the literature, an explicit agreed-upon definition for CSA is difficult to find. Computer simulation and animation (CSA) is a general and broad name for computer applications that include animated graphics as well as text information to model a real phenomenon through graphical means. A "computer simulation" is supposed to accept inputs, incorporate those inputs into

calculations or modeling, and present functional outputs^{22, 23}. Compared to “computer animation”, “computer simulation” is usually more calculation-oriented to characterize the real phenomenon of interest.

Another advantage of a CSA application is its ability to be replayed, offering students a replicable, structured, and visual experience for obtaining information. CSA modules are typically characterized by: (1) using animations to illustrate key concepts; (2) interacting with users to enable users to change one or more input parameters to alter animation and/or calculation details; (3) enabling users to navigate through modules to review; and (4) presenting more information to users through clickable pop-out boxes. The last three characteristics focus on students’ active involvement, giving them a chance to organize their learning process by navigating through modules, changing input parameters, and observing the outcomes. Depending on the technical limitations and CSA objectives, different researchers have focused on different aspects of the above-mentioned characteristics^{6, 11, 12, 17, 18, 24}.

Pedagogical innovations in the instruction of engineering mechanics

Before 1990’s, the main emphasis of educational research was on improving teaching styles, active learning, and facilitation of student conceptual understanding²⁰. Developments in computer graphics and web-based tools have reinforced these efforts with slight structural changes in the past two decades. There are a large number of research studies focusing on overall change in engineering curricula; for example, a new core curriculum design was introduced by Belytschko et al.²⁵ The following sections provide a description of representative pedagogical innovations in three categories: (1) altering the engineering mechanics curriculum, (2) active learning strategies, and (3) the application of enhancement resources.

Altering the engineering mechanics curriculum

Besides changes to the entire curriculum, improvement strategies for engineering mechanics address other aspects of pedagogy, such as developing new course sequences, creating hands-on simulation tools, and introducing novel instruction approaches. Changing the sequence of topics in engineering mechanics is one solution to create more integrity within the engineering mechanics course^{4, 25, 26}. Cornwell⁴ described the new distribution of topics in mechanics courses and demonstrated the improvements made possible by a new sequence of curriculum. In an effort to span over freshman and sophomore years courses, Belytschko²⁵ developed a curriculum by integrating a subset of mathematics and science with engineering. It targeted engineering design to foster freshman year students through a four-course sequence called “Engineering Analysis”²⁵.

Nonetheless, changes in curriculum face two major challenges. First, it is difficult to assess the impact of curricular changes in a short time, and no pretest-posttest experiments can identify the impacts of a curricular change on multi-course span. Second, changes in curriculum need to engage those parties impacted by the change who are outside academia to consider their concerns as well as those of the faculty and departmental leaders²⁷. Since curricular changes are related to attitudes and skills as well as the content materials, not all faculty members can accept the intense, yet required integration of new attitude and skills within the content change. Therefore, the studies addressing entire curriculum changes are infrequent in the recent years²⁷.

Employing active learning strategies

Student involvement is perceived to be an effective tool in all levels of education^{20, 21, 22, 23}. Although, involving students in course activities or active learning requires innovative changes to the course examples and problems. Howell⁵ introduced five basic elements to consider in cooperative learning: positive independence, face-to-face interaction, individual accountability, collaborative skills, and group processing. Since there is a large volume of problem solving in engineering mechanics, cooperative problem-solving practices can be implemented suitably³. Structuring a lecture class devoted to cooperative learning groups can be overwhelming to many instructors, but introducing cooperative problem solving receives unexpected positive feedback from the students' side. This phenomenon supports the fact that almost all novel teaching techniques can reinforce conventional pedagogy, but none can be used as substitute methods¹⁹.

Incorporating a design challenge, along with altering the sequence of topics and adding group activities with a broader range of resources, is another method that may work to create an innovative teaching style. A more recent initiative, studied over three years from 2008 to 2011, introduced team-based assignments to students²⁷. In that study, groups of up to five students were given a design challenge directly related to a specific topic in engineering dynamics. These challenges proved to be popular among students and led to improved learning outcomes and improved student performance without compromising academic standards^{26, 27}. Deploying research-led methods in teaching is successful in relating current coursework to actual engineering problems for both undergraduate and postgraduate students.

All new methods which claim to improve pedagogy are based on one of the theories of learning, e.g., behaviorism, cognitivism, and constructivism^{23, 28}. The context of active learning vs. reflective learning is focused in most of the studies, although it is not explicitly stipulated in most of the papers. In one study²⁸, active learning strategy method was combined with computer-assisted learning to foster engineering students' conceptual understanding. Eronini²⁸ introduced a simple design project and demonstrated the improvement in student performance due to his intervention. The mechanism of improvement relied heavily on raising motivation and enthusiasm among students by involving them in the course material not only as viewers but also as active players. Students were provided an opportunity to feel oriented and purposefully conducted the design. Introduction of design issues had little impact on the course content and learning concepts²⁸.

Applying enhancement resources

As mentioned in the previous section, computer-aided instruction involves developing assignment problems involving the use of parametric solutions to the problems, thus guiding students to use computers to reformulate a problem in terms of non-dimensional parameters. In this regard, average students show more interest in computer-assisted problem-solving challenges⁷. Several computer tools have been developed to maintain student involvement in engineering mechanics, combining lab activities with CSA in an authentic project^{15, 28, 29, 30}. The main educational advantage of using computer-based labs is the real-time display of experimental results and graphs, facilitating a direct connection between the real experiment and

the abstract representation¹⁹. Nevertheless, acquisition of laboratory skills is often a learning goal in itself which cannot be completely replaced by simulations.

It is a common pedagogical practice to use analogies. In this regard, engineering mechanics is no exception. In Dabney's study¹⁴ analogies were the physical phenomena from which equations were initiated. Another feature of the analogy approach is its claim of increasing students' confidence in the concepts they have learned. Besides tool-based pedagogical improvement, e.g. computers, labs, and CSA, peer-guided discussions have been studied as an effective human-based method to promote students' active involvement in engineering dynamics^{31, 32}.

Streveler et al.³³ studied learning tools more from the aspect of cognitive learning theory. By studying students' learning difficulties in engineering dynamics, it was concluded that three issues cause difficulties or misconceptions among students³³. The first issue is the failure to make proper distinctions between different objectives expected from the same phenomena in different discourses. The second issue is the misunderstanding of the meanings of two different concepts due to the closeness of their respective implications; for example, mixing heat and temperature. The third issue is that many students have difficulties in conceptualizing phenomena that are not directly sensed but are usually mathematically represented and analyzed. A good example of the third issue is "angular momentum," a topic covered in engineering dynamics³³.

Focusing on engineering mechanics teaching techniques, concept questioning and scenario building are suitable techniques to create interactive CSA modules with rich graphical content⁹. Animation modules created in this way can cover engineering mechanics courses including statics, strength of materials, and dynamics^{25, 34}. By analyzing student feedback through surveys, Sidhu et al.³⁵ concluded that this approach to teaching and learning helped students increase their ability to understand dynamics concepts. Deliktas¹⁷ claimed that it also assisted instructors in conveying their ideas more conveniently, which is important because materials and modules produced cannot replace the conventional teaching practices. Deliktas¹⁷ suggested that CSA modules are supportive materials and can merely enhance pedagogy. Many studies which aim at the improvements of pedagogy target problem-solving enhancement methods because of the importance of problem solving in learning³¹. Applications of CSA tools mainly focus on the "problem representation" dimension of problem solving²⁰.

Computer applications as learning tools in engineering mechanics education

Applications of computers in higher education include online education, virtual classrooms and E-learning, multimedia, animations and simulations, as well as learning games and online tutoring systems^{19, 23, 34, 35}. Almost all of these applications have been assimilated in engineering mechanics. Although in early 1990s, when computer-aided instruction tools started to emerge, research studies reported slight positive impacts due to computer applications, a situation which has now changed drastically^{18, 10, 2, 16}. Use of modern educational tools, such as simulation software models and visualization techniques, is not only effective but is also often required in engineering mechanics course curricula to assist students in understanding the engineering aspects of dynamics. The following is a list of reasons posited by several researchers:

- Although mechanical models used in either the classroom or the lab help a lot, they have little flexibility, and they are mostly qualitative, not quantitative. They are not easily repeated, and reinstalling and redoing of the experiments is not simple³⁶.
- Students' learning styles are different in many ways such as watching and hearing; analyzing and acting; reasoning logically and intuitively; memorizing and understanding and drawing analogies; and building mathematical models¹⁷.
- In engineering dynamics, most of the content concerns motion, but textbooks, chalkboards, and the traditional classroom teaching tools cannot easily show that motion⁷.
- While working with a computer simulation application, students can adjust the pace of the content representation to the desired level.
- Computer simulation applications can be combined with physical laboratory experiences effectively⁹.

Computer simulation and animation

Developers of educational animations have focused on the capabilities of user-friendly motion visualizations and the attractiveness of text-animation combinations in order to promote their applications^{7, 9, 37, 38, 39}. More complex capabilities, such as 3D representation and rendering, were added to animations thereafter, which improved the learning impact of animations and simulations^{22, 38, 39}. In the past decade, interactive features have been added to CSA modules, which increase their effectiveness as well as students' involvement with these modules. Costanzo⁸ identified five necessary characteristics for computer-based learning: (1) hands-on laboratory experience, (2) a multidisciplinary approach, (3) systems perspective, (4) an understanding of information technology, and (5) an understanding of the importance of teamwork. It can be seen that many investigations focus on these characteristics.

Visualization characteristics of CSA modules can be associated with cognitive science aspects such as schemata; mental and graphic visualization, reflection and debriefing, situated learning or cognition, and cognitive apprenticeship^{23, 40}. Brown⁴⁰ noted the infrequency of visualizations integrated into classroom instruction. He attributed this infrequency to the lack of sufficient teaching tools. Without exposure to them, students could not experience the benefits of useful CSA tools. In addition, new modules have included more web-based interactive tutoring^{23, 35, 38}. For example, the tutorial package developed by Ong³⁸ could support students with an interactive feature with the capability of modifying parameters so that a user can monitor how the solution changes concurrently. In demonstrations of engineering mechanics, changes in input parameters can change the motion of objects or result in pop-up textual or graphical data^{38, 29}. The interaction features of CSA modules can be developed to introduce problems, give feedback on a user's response, and perform smart tutoring by checking different solution scenarios.

In addition to using CSA and multimedia tools, several modules have been developed and tested to build a more effective classroom environment^{17, 41}. Almost all researchers of CSA tools have attempted to measure the efficiency of their represented computer tool. The majority of the developed CSA modules are assessed through feedback and interviews provided by end users^{18, 42}. Feedback is highly biased and dependent on other pedagogical factors, such as teacher aesthetics, course content, student motivation, etc. Nevertheless, in the future, there will be widespread use of virtual classroom computer modules at the college level²³.

Comparing student performances in engineering mechanics with and without CSA modules demonstrates that learning with properly-created, interactive animations has positive effects on most students' academic performance^{9, 42}. CSA can deliver information in a very attractive way, which is advantageous in assembling curricula for students who have different skill levels and learning styles. Properly-developed CSA can help learners to understand scientific topics by presenting important conceptual relationships and enabling students to become acquainted with the shown system and make changes in input parameters with no additional costs or risks^{42, 43, 44}. There is no standard procedure for creating successful visual applications, although in order to have the desired effect, CSA modules should be: (1) covering topics that include dynamic characteristics; (2) comprising a limited multitude of colors; and (3) giving an optimal amount of text information. A number of studies indicate that if the teaching method matches a user's learning style, the user's performance is much better. CSA containing a lot of visual components, such as pictures, diagrams, etc., are preferred for the visual learning profile, while written and auditory explanations are effective for the verbal type of student^{17, 39, 42}.

Learning games and virtual reality

Learning games have also been considered in computer-based learning. Games are interactive, include animations, foster student involvement, and stimulate student motivation. These reasons make games an attractive choice for educators. A comprehensive list, along with the characteristics and challenges of existing game environments, is presented by Deshpande⁴². In engineering mechanics, there are two game modules for helping students grasp the fundamental concepts and basic calculations. Research studies related to the development of games reported positive feedback and increased performance from participants in nearly every engineering discipline⁴². A major issue in the design of educational games is that a close collaboration between module developers and text book authors is needed to provide more concrete, consistent material in both products. Instructors with programming knowledge can develop attractive and effective games which target students' misconceptions. Particularly in engineering dynamics, the games which include calculation challenges can introduce more complex real life engineering problem-solving as well as addressing students' misunderstandings in basic topics such as force, acceleration and velocity⁴⁵.

As another attractive computer tool, virtual reality (VR) simulations and animations enhance a student's capabilities in programming and operations without the need to work on actual laboratory equipment. VR simulations also improve a student's concentration and ability to generate interactions concurrently, similarly to simulation practice in authentic trainings, such as flight simulations in pilot training³⁸. Nevertheless, the common flaw among all these tools is that the procedure of setting up a complex computer simulation or a web-system for e-education requires a significant amount of time¹². It also requires the use of appropriate pedagogical models and principles along with appropriate means of communication between participants and instructors and deep knowledge of learning theories. Participant-researcher communication is illustrated in the design of a technique called the "Zaltman Metaphor Elicitation Technique (ZMET)" which produces a consensus map of the participants' concepts⁴⁷. The consensus map contains the links between system attributes, usage consequences, and personal values^{46, 47}. Although beneficial to students' conceptual understanding, VR tools may have limited effects on practices requiring student analysis and synthesizing knowledge^{39, 47}.

Virtual online assistants, which help students imagine different concepts in engineering mechanics, have been studied significantly. Such assistants act as computer tutors; for example, Roselli²⁷ developed an online Free Body Diagram (FBD) assistant to help students construct 2D FBDs. The assistants provided feedback for a wide range of practice problems, helping improve both learning and assessments. CSA modules can be used in a senior year course as well as at the graduate level¹¹. It is important to use an appropriate software package to develop the learning interface based on the students' backgrounds and prior knowledge of the subject. Stern et al.¹¹ posited that lecture and lab teaching were more suitable for courses at introductory and undergraduate levels, and multimedia and simulation modules were appropriate for courses at graduate levels.

More rigorous VR animations and simulations are increasingly used in teaching advanced engineering courses such as machine design. A good example is “virtual reality” simulations and animations for understanding complex 3D design concepts³⁸. Fang et al.¹¹ designed a semi-structured interview to capture participants' learning experiences with a simulation-based learning (SBL) module. Fang et al.¹¹ argued that SBL not only enlivened the learning of machining technology, but it also promoted autonomous learning and mastery. Furthermore, use of SBL made a deep impression on the participants' visual experience, helping them remember the machine processes. The autonomy given by a virtual tool enhances participants' construction of knowledge^{11, 23, 38}.

Literature Analysis

Review of the existing literature about CSA applications in engineering mechanics education shows that the main objective of CSA modules is to help students visualize key concepts. From the Bloom taxonomy viewpoint, visualization is associated with the understanding level⁴⁹. The textual information helping the student remember basic concepts or confirming their previous knowledge can be linked to the knowledge level¹¹. Interaction features enable students to engage in the solution process and observe the changes they make. Although, few studies associate this feature to the cognitive domain level of application^{11, 12, 22}, almost all studies address it from the practical point of view. Interactive features also enables the user to repeat a specific part any number of times with different input parameters. In Bloom's taxonomy of educational objectives⁴⁹, the next level after application is evaluation. If we attribute interactive feature in CSA modules to the “application” level, it can be concluded that instant feedback to the student would address the “evaluation” level. Therefore, like many CSA applications currently used in science education¹⁸, future CSA modules in engineering mechanics will give feedback regarding the user's solution to problems.

Relationship between learning theories and CSA modules

The theoretical framework of a learning tool or model highly affects its effectiveness. While most instructors emphasize on the practical outcomes of CSA modules, cognitive learning theories influence their instructional design significantly. Three learning theories in educational psychology are: Behaviorism, Cognitivism, and Constructivism²³. The number of researchers who cite these theories in their studies is exceptionally small.

Table 1 shows the learning theories addressed in relevant papers which introduce a computer-based pedagogical application. It is shown that 80% percent of studies do not mention a theoretical framework while introducing the applications²³. Instructional design of a module naturally targets a cognitive skill. However, in order to determine the level of effectiveness of a CSA application, the associated changes in the student’s performance in problem solving or in exams are measured, which fits the Behaviorism theory.

Table 1. Theoretical consideration in CSA papers

Course	Number	Percent	Addressing learning theories		
			Explicit	Implicit	None
Dynamics	12	60%	3	7	2
Mechanics of material	2	10%	-	1	1
Statics and dynamics	1	5%	-	-	-
All three courses	2	10%	-	1	2
Other engineering mechanics	3	15%	1	2	-
Total	20	100%	4 (20%)	11(55%)	5(25%)

Felder and Silverman’s learning style theory^{20, 23} cites four dimensions in learning styles: (1) sensory/intuitive, (2) visual/verbal, (3) active/reflective, and (4) sequential/global styles. Most CSA applications cover the first three styles. In fact, as shown in Table 2, most studies address ‘visual/verbal’ and ‘active/reflective’ dimensions either explicitly or implicitly. Nevertheless, the ‘sequential/global’ dimension receives less focus in design of current CSA application in engineering mechanics.

Criteria of effective CSA modules

Besides improving visualization, most CSA modules introduced in the literature meet the following criteria: (1) interactivity, because an effective CSA module would be interactive, giving autonomy to the user to adjust the pace of navigation with his/her own learning^{7, 9, 11, 23}, (2) simplicity, which is a helpful feature because an information flood within a CSA module will distract and discourage the user from the intended content, and (3) a critical balance between textual and graphical information, which can be facilitated by pop-out boxes^{17, 24}. If the user feels a need to have more explanation on a certain subject, he/she can click on it. Otherwise, the main idea will attract the user through animated or fixed graphical representation.

Assessment of effectiveness

In Table 3, the adopted assessment methodologies are shown in articles which introduce an innovative CSA module or a computer simulation technique. The table shows that a majority (76%) of these studies employ a quantitative approach as the main research method, and more than half (56%) of the studies use replies to questionnaires and positive feedback to infer the

Table 2. Theoretical consideration in CSA papers

Learning theory mentioned	Number of papers	Percent
Addressing several learning theories	4	20%
Implicitly addressing learning style theory: visualization	5	25%
Implicitly addressing learning style theory: problem solving	6	30%
No learning theory mentioned	5	25%
Total	20	100%

effectiveness of their modules^{9, 10, 11, 16, 17, 24, 28, 29, 30, 34, 35, 36, 50, 51, 52}. A small percentage of the studies (9%) use an observation-based qualitative approach as an assessment means.

Regarding developments in teaching engineering mechanics, i.e. statics, dynamics, and strength of materials, efforts made to improve student performance are grouped into three major categories: (1) altering the engineering mechanics curriculum, (2) active learning strategies, and (3) the application of enhancement resources. The first category addresses combining topics of instruction, changing the course sequence/design, and introducing problem/project-based learning in engineering mechanics. The second category involves students in the learning process through hands-on projects, fostering problem-based learning, and team work. Finally, introducing lab experiences, integrating authentic design projects, and fostering conception through video or CSA modules can be grouped within the third category.

The research gaps

Three research gaps were observed based on published CSA-related papers. The first research gap is that although most of the studies implicitly noted the “learning style” concept, very few of them cited a “learning theory” framework and explained if and how this framework was employed to design their CSA modules.

The second research gap is the lack of a methodology for selecting disciplinary topics when designing CSA modules. Except for the papers which cover all concepts in a particular course, only two papers address the methodology of selection of the disciplinary topics for which CSA modules are designed^{50, 55}. Almost all reviewed papers focus on the difficulty or importance of their selected topics based on the researchers’ experience.

The third research gap is that CSA modules introduced in the studies were assessed primarily using student feedback and comments. Few studies employed a qualitative approach to address how student cognitive skills can be improved by CSA modules. In other words, the question of “how exactly CSA helps students with learning?” remains unanswered.

Table 3. Papers introducing new tool/methods with their assessment methodology

Field	Reference number	Assessment method			
		Questionnaire	Observation	Learning-gain comparison	No assessment
Statics and Dynamics	[28], [33], [55]	1	1	1	-
Dynamics	[2],[8],[9],[16],[17],[22], [24],[30],[34],[35],[36], [39],[41],[43], [47], [50], [53], [54]	10	-	4	4
Mechanics of materials	[4], [7], [23], [44], [51], [51]	2	2	2	-
Other engineering mechanics	[10],[11],[13], [14], [29],[38]	5	-	-	1
Percentage		55%	9%	21%	15%

Conclusions

The above literature review focusing on CSA and other pedagogical innovations in engineering mechanics education reveals that:

- Because of the complexity of concepts, engineering mechanics courses are suitable courses for using CSA modules as pedagogical tools. Particularly in engineering dynamics, CSA modules can demonstrate motion of particles and rigid bodies through computer animations, helping students picture the concepts taught in the course.^{23, 35}
- All studies suggest that interactive features, animation, and problem solving are the main characteristics of effective CSA. Although learning theories affect the instructional design of CSA modules, they are not often addressed in published research papers.
- Most researchers posit that CSA modules cannot be considered as the sole pedagogical tool, and that CSA modules cannot replace conventional classroom instruction. Most ideally, typical face-to-face or online classes combined with novel improvements, such as peer help or group problem solving, can be complemented by CSA modules³².
- Face-to-face instruction can provide “learning evaluation” to students. “Learning evaluation” which is a major component in cognition, is not yet incorporated in most CSA modules. It is anticipated that by incorporating instant feedback capability will reinforce CSA applications.
- While it is common to use students’ performance change and self-reported questionnaires to evaluate the effectiveness of CSA modules, they cannot express the modality of CSA effects on students’ learning process. Overall evaluation results may be subject to Hawthorne effects, which means participants’ responses may be affected by the attention they received as study participants. A more thorough and rigorous assessment of the effectiveness of CSA modules requires investigating the modality of the effect of CSA

modules on students' thinking. A rigorous research design would involve the use of pre- and post-test experiments and involve a theoretically-intensive, highly-organized qualitative approach.

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