Title:
Use of SOLIDWORKS to Connect Courses in Mechanical Engineering Program

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Introduction:
CAD/CAM/CAE systems have been widely used in industries for design, manufacturing and analysis of mechanical products and systems such as automobiles and airplanes. In these industries, virtual prototypes of complete products and systems are usually developed for evaluation and optimization before physical prototypes are produced.

In mechanical engineering programs, CAD/CAM/CAE systems are primarily used for courses in the areas of design, manufacturing, and analysis, such as engineering graphics, CNC machining, finite element analysis (FEA), and computational fluid dynamics (CFD), as well as project-based design courses. For many fundamental courses in mechanical engineering, since the theoretical foundations are focused, students are required to solve problems in these courses by hand or by standard computer programs such as MATLAB rather than using the CAD system as a black box tool.

With the trend of education change from traditional knowledge-based learning to modern application-based learning [2], design projects are often introduced to the fundamental courses to employ the learned knowledge to create solutions from real-world requirements [1]. CAD/CAM/CAE systems are effective tools for solving engineering problems with complexity in these design projects.

The objective of this study is to investigate the topics in mechanical engineering courses and the functions in SOLIDWORKS to identify the relations between the mechanical engineering topics and the SOLIDWORKS functions. The results from this work can be used for developing design projects in the mechanical engineering courses and connecting these courses through cross-course design projects.

Considerations for Selection of SOLIDWORKS as the Tool:
SOLIDWORKS [4] is selected as the tool to connect courses in mechanical engineering programs based on the following considerations.

(1) Short Learning Time

- Unlike other popular systems such as CATIA, NX (formerly Unigraphics), and Creo (formerly Pro/ENGINEER), which were first implemented in the UNIX environment, SOLIDWORKS was designed as a native Microsoft Windows application with user-friendly interfaces.
- SOLIDWORKS provides relatively short and comprehensive online tutorials, such that students can learn most of the fundamental functions in a short time period.

(2) Broad Spectrum of Functions to Cover Mechanical Engineering Topics

- SOLIDWORKS provides a broad spectrum of fundamental functions to cover various areas in mechanical engineering, including solid mechanics and thermofluids, in addition to design and manufacturing, although some functions in certain areas are limited compared with specialized tools (e.g., ANSYS is a more powerful system for FEA and CFD).
- SOLIDWORKS provides an extensive toolbox library (e.g., components of gears and bearings, and mating conditions to build gear-pair mechanisms and cam-follower mechanisms) for rapid

development of mechanical products and systems.

In addition, SOLIDWORKS is a popular CAD system selected for the engineering graphics courses in the early years of the mechanical engineering programs.

Mechanical Engineering Program and Fundamental Mechanical Engineering Courses:

Mechanical Engineering Program

A mechanical engineering program in Canada [3] is usually composed of courses in the following categories:

- Design with projects: first-year introduction to design, final-year capstone design
- Mathematics: calculus, probability, and statistics, linear algebra
- Science: physics, chemistry
- Computing: programming, engineering computing tools, numerical methods
- Fundamental mechanical engineering: engineering graphics, statics, kinematics, dynamics, mechanics of materials, mechanisms and machine design, machine component design, materials, control, engineering thermodynamics, heat and mass transfer, fluid mechanics, vibrations, manufacturing processes, mechatronics
- Advanced mechanical engineering: robotics, CNC machining, finite element analysis, computational fluid dynamics
- Other engineering: electrical circuits
- Others: economics, technical writing, technology and society, ethics and professionalism, humanity

Fundamental Mechanical Engineering Courses

The fundamental courses form the core of a mechanical engineering program, equipping students with the essential knowledge needed to design mechanical products and systems for their future careers. These fundamental courses can be grouped into the following categories:

- Solid Mechanics: statics, kinematics, dynamics, mechanics of materials
- Thermofluids: engineering thermodynamics, heat and mass transfer, fluid mechanics
- Design and Manufacturing: engineering graphics, mechanism and machine design, machine component design, manufacturing processes
- Others: materials, control, vibrations, mechatronics

SOLIDWORKS and Functions of Its Modules:

SOLIDWORKS products used in this investigation include: SOLIDWORKS Premium, SOLIDWORKS Simulation Premium, SOLIDWORKS Flow Simulation, SOLIDWORKS CAM Professional, and SOLIDWORKS MBD Standard. Various modules are provided in these SOLIDWORKS products.

SOLIDWORKS Premium

- Modeling: geometric modeling of parts, assemblies, and drawings
- TolAnalyst: evaluation of the cumulative effects of dimensions and tolerances in assemblies
- Toolbox: library of standard components such as gears, bearings, bolts and nuts, and screws
- PhotoView 360: creation of a high-quality, photorealistic image of the 3D model
- Motion: motion simulation and analysis of assemblies
- Sheet Metal, Weldment, Mold: modeling of parts considering their manufacturing processes
- ScanTo3D: conversion from 3D scan data to parametric CAD model
- Costing: estimation and management of the manufacturing costs of parts and assemblies

SOLIDWORKS Simulation Premium

- Static: static analysis of the effects of loads on displacements, stresses, and strains
- Frequency: analysis of the natural frequencies and vibration modes of a part or assembly
- Buckling: prediction of the critical load at which a structure may become unstable and collapse
- Thermal: analysis of the temperature distribution and heat transfer within a part or assembly under steady-state or transient conditions

- Drop Test: study of the impact of dropping a part or assembly onto a rigid surface
- Fatigue: assessment of the life of a part or assembly under repeated loading
- Dynamic: simulation of the effects of time-dependent loads or accelerations on a structure
- Optimization: identification of the optimal design parameter values to achieve the optimal goal (e.g., maximization of performance and minimization of cost) while satisfying constraints
- Harmonic: study of the structural response to sinusoidal (cyclic) loads with a range of frequencies

Others
- Flow Simulation (in SOLIDWORKS Flow Simulation): analysis and simulation for the flow of fluids (liquids and gases), heat transfer, and forces acting on parts and assemblies
- CAM (in SOLIDWORKS CAM Professional): CNC machining of parts with milling and turning operations
- DimXpert (in SOLIDWORKS MBD Standard): dimensioning and tolerancing for 3D models

Topics in Mechanical Engineering Courses and Supporting Functions in SOLIDWORKS:
Relations between the topics of mechanical engineering courses and the available functions of SOLIDWORKS have been investigated. SOLIDWORKS in these courses is used for two purposes:
- Verification of the results calculated by hand or by a standard computer language
- Real-world problem solving through design projects

In this study, the fundamental courses in mechanical engineering are focused. The relations are summarized in Table 1.

Table 1: Relations between mechanical engineering topics and SOLIDWORKS functions.

Course	Topics	SOLIDWORKS
Engineering Graphics	Parallel and perspective projections. Multiviews. Auxiliary views. Section views. Assembly drawings. Exploded view.	Modeling
	Dimensions. Tolerances.	DimXpert, TolAnalyst
	Standard components (e.g., gears and threads).	Toolbox
Statics	Forces and moments in beams. Truss analysis. Calculation of distributed loads and pressures.	Static
	Center of mass. Moment of inertia.	Modeling
Kinematics	Positions, velocities, and accelerations in linear and rotational motions.	Motion
Dynamics	Forces and torques for rigid bodies with motions. Kinetic energy, potential energy, and power.	Motion
	Impact and collision analysis.	Drop Test
Mechanics of Materials	Normal stress, shear stress, and strain. Elastic deformation. Factor of safety.	Static
	Buckling.	Buckling
	Fatigue.	Fatigue
Mechanism and Machine Design	Kinematic and dynamic analysis. Linkage mechanisms. Gear trains. Cam-follower mechanisms.	Motion
Machine Component Design	Spur gears, helical gears, and bevel gears. Roller and ball bearings. Threaded fasteners (e.g., bolts, nuts and screws). Power screws. Rivets. Keys and keyways.	Toolbox
	Shafts. Springs.	Modeling
	Welded joints.	Weldment
Engineering Thermodynamics	Calculation of parameters (e.g., pressures, temperatures, and densities) of a thermodynamic system with components (e.g., turbines, compressors, and nozzles). Combustion and cyclic analysis are not supported.	Thermal, Flow Simulation
Heat and Mass Transfer	Conduction, convection, radiation, and diffusion.	Thermal, Flow Simulation

Table 1: Relations between mechanical engineering topics and SOLIDWORKS functions (continued).

Course	Topics	SOLIDWORKS
Fluid Mechanics	Calculation of parameters (e.g., velocities, pressures and temperatures) at different locations considering various types of flows (e.g., external and internal flows, steady state and transient flows, and laminar and turbulent flows) and fluids (e.g., ideal and real gases, single or multiple species, incompressible and compressible fluids, and non-Newtonian fluids). Fluid system with rotating devices (e.g., fan). Fluid system in porous media. Fluid analysis with heat transfer.	Flow Simulation
Vibrations	Modal analysis for obtaining natural frequencies of a system and its corresponding mode shapes.	Frequency
	Steady-state response with harmonic loads or vibrations.	Harmonic
	Transient analysis. Forced vibration analysis.	Dynamic
Manufacturing Processes	Casting and molding process.	Mold
	Sheet metal.	Sheet metal
	Welding.	Weldment
	Additive manufacturing.	ScanTo3D
	Milling and turning.	CAM
	Estimation of costs considering different processes.	Costing
Materials	*The core topics in this course are not supported by SOLIDWORKS functions.*	
Control	*The core topics in this course are not supported by SOLIDWORKS functions.*	
Mechatronics	*The core topics in this course are not supported by SOLIDWORKS functions.*	

SOLIDWORKS can also be used for other courses in the mechanical engineering program including the advanced mechanical engineering courses and the capstone design course. The relations between topics of these courses and available functions of SOLIDWORKS are summarized in Table 2.

Table 2: Relations between topics in other courses and functions in SOLIDWORKS.

Course	Topics	SOLIDWORKS
Robotics	Kinematics, statics, and dynamics for robotic systems.	Motion, Static
CNC Machining	Modeling, simulation, and CNC code generation considering milling and turning operations.	CAM
Finite Element Analysis	Fundamental FEA analysis.	Modules in Simulation
	Geometric modeling for advanced FEA with ANSYS.	Modeling
Computational Fluid Dynamics	Fundamental CFD analysis.	Modules in Flow Simulation
	Geometric modeling for advanced CFD with ANSYS.	Modeling
Numerical Method	Optimization with variables, objective function, and constraints.	Optimization
Capstone Design	Modeling and analysis for design projects.	All Modules

SOLIDWORKS for Fundamental Mechanical Engineering Courses at the University of Calgary:

Among all the courses required to complete the mechanical engineering program at the University of Calgary, Canada, the fundamental courses in mechanical engineering are investigated in this study, as shown in Table 3. The various SOLIDWORKS modules that can be used in these courses are given in Table 4. Connection of these courses through SOLIDWORKS has the potential to achieve the following goals:

- Since SOLIDWORKS is introduced in the second-year ENME 339, students can use it together with the learned theoretical knowledge in the relevant courses to solve real-world problems through course projects.
- Since some courses in the mechanical engineering program are integrated into clusters with cross-course projects, SOLIDWORKS can be selected as the common tool for these projects.

Table 3: Fundamental courses related to mechanical engineering at the University of Calgary.

Category	Courses
Solid Mechanics	ENGG 202 Engineering Statics. ENME 317 Mechanics of Solids I. ENME 479 Mechanics of Solids II.
Thermofluids	ENME 341 Fundamentals of Fluid Mechanics. ENME 471 Heat Transfer. ENME 485 Mechanical Engineering Thermodynamics. ENME 495 Fluid Mechanics.
Design and Manufacturing	ENME 339 Engineering Graphics and CAD. ENME 473 Fundamentals of Kinematics and Dynamics of Machines. ENME 493 Machine Component Design. ENMF 417 Manufacturing and Production Processes.
Others	ENME 421 Materials I. ENME 461 Mechatronics for Measurement and Instrumentation. ENME 585 Control Systems. ENME 599 Vibrations and Machine Dynamics.

ENGG: Engineering Common Course, ENME: Mechanical Engineering Course, ENMF: Manufacturing Engineering Course

Table 4: SOLIDWORKS modules for the fundamental courses.

SOLIDWORKS	Courses
Modeling, PhotoView 360, Optimization	All courses
DimXpert, TolAnalyst	ENME 339
Toolbox	ENME 339, ENME 493
Motion	ENME 473
Sheet Metal, Mold, CAM, ScanTo3D, Costing	ENMF 417
Weldment	ENME 493, ENMF 417
Static	ENGG 202, ENME 317, ENME 479
Frequency, Harmonic, Dynamic	ENME 599
Buckling, Fatigue	ENME 317
Thermal	ENME 471, ENME 485
Flow Simulation	ENME 341, ENME 495

Conclusions:

In this study, the topics in mechanical engineering courses, the functions in SOLIDWORKS, and the relations between the topics in mechanical engineering courses and the functions in SOLIDWORKS have been investigated. Findings from this study are summarized as follows.

- Because SOLIDWORKS has a short learning curve and offers comprehensive functionality, it is an appropriate tool for use in various mechanical engineering courses, where design projects can complement traditional theory-based learning by solving real-world engineering problems efficiently.
- Because SOLIDWORKS provides a broad spectrum of functions to cover various mechanical engineering topics, it can be used to connect these courses through cross-course design projects to solve real-world engineering problems with complexity.

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