34th Australasian Association for Engineering Education Conference
3 - 6 December 2023 – Gold Coast, QLD

On the 3D printing models and students' learning

Nirmal Kumar Mandal; M. G. Rasul
Central Queensland University, School of Engineering and Technology, Rockhampton, Queensland, 4702
Corresponding Author Email: n.mandal@cqu.edu.au

ABSTRACT

CONTEXT

Engineering education employing 3D printing models has emerged as an innovative teaching practice for student learning and problem-solving. Embedding it into the engineering curriculum helps improve the learning space for higher education sectors. The benefits of students' learning in all disciplines such as Mechanical, Civil, Electrical, Chemical, and Mechatronics engineering are evident. The scope of employing this pedagogy expanded in other areas as well such as podiatry, and health sectors. The benefits of this pedagogy are the students' learning in problem solving, and students' skills to turn engineering theories into practice.

PURPOSE OR GOAL

Scopes of employing 3D printing technologies are expanding in various modes: teaching students and educators about 3D printing, supporting technology during teaching, producing artifacts/models for student learning, creating assistive practices, and supporting outreach activities. The focus of this study is to evaluate the impact of 3D models' influence on mechanical engineering students learning and developing problem-solving skills.

APPROACH OR METHODOLOGY/METHODS

The 3D printing models are prepared using 3D printing technology in relation to the content of the weekly lectures and tutorials on the Solid Mechanics unit. Each week. A few important models are introduced to on-campus students through hands-on activities and distant students through video cameras to demonstrate problem definitions, scopes, and failure modes of structural members under loading. Student feedback, reaction, and satisfaction are obtained on a yearly basis for the evaluation of 3D printing models' impact on student learning using unanimous unsolicited university student data. The trend, value, and meaning of student data and the improvement of student reactions are compiled for future actions.

ACTUAL OR ANTICIPATED OUTCOMES

As the 3D models changed the mode of students' learning from a 2D textbook view to a wider 3D view of 3D printed models, the student can clearly see the failure surface and the direction of applied forces from various angles. Their idea and learning are improved. Students' interest in the Solid Mechanics unit is expected to increase gradually, which helps lifelong learning.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The applications of 3D printing models in classroom activities significantly impact student learning and problem-solving skills. Because of the new pedagogy of teaching method, the students are interested more in the unit contents and improve their capacity to put engineering theory into practice in industrial applications.

KEYWORDS

3D printing models, students learning, a new pedagogy of teaching, and student problem-solving skills.

Introduction

A new teaching approach to developing students' interest in subject content and learning is important. The students' reactions and feedback on teaching approaches and content can be helpful for further improvement of future offerings. The adoption of 3D printing models and additive manufacturing (AM) is emerging as an engagement tool for a new teaching practice at schools, and universities including science, technology, engineering, arts, and math (STEAM) (Ramey and Stevens, 2019). For enhancing the teaching practices and students' satisfaction and learning, the 3D printing models along with a good student engagement approach are necessary (Mandal, 2018 and Mandal, 2021). The 3D printed model framework develops student interest and enhances students' curiosity to learn in lower-level engineering units such as Structural Mechanics at CQU. The student cohort is from various phases such as school leavers, mature-age students, and students from diverse cultural backgrounds. These students are in both distance and multi-campus modes (Rockhampton, Gladstone, Bundaberg, Mackay, and Cairns).

Innovative teaching practices incorporating 3D printed models are recognised widely. The impact of this approach has extended nationally and internationally (Mandal, 2019, Ford and Minshall, 2019, Ramey and Stevens, 2019, Ozeren, et al., 2023). One session chair of the Australasian Engineering Education Conference in Geelong, Victoria in 2015 argued that the innovative approach using 3D printed models could be most useful for Australian Universities. Pantazis and Priavolou (2017) pointed out that the 3D printing models can encourage meaningful communication and learning among high school students in Greece.

3D modelling technology is emerging as an innovative tool to connect theory to practice. The theory relating to 3D views and spatial recognition, textbook diagrams, and three-view diagrams limit the effectiveness of the teaching materials (Huang and Lin, 2017). Students follow passive learning methods of imagining a 3D view of a real structure. This can lack the students' ability compared to that of 3D and spatial presentations. The authors argued that the teaching methods incorporating 3D printed solid models developed students' spatial ability and learning outcomes. They also pointed out that this outcome was better than that of a traditional method of using three-view diagrams.

3D printing in the health sector has a wide impact. It can assist in surgery effectively (Lin, et al. 2018, AlAli, et al. 2018, Garas, et al. 2018, Langdon, et al. 2023). The authors investigated the use of 3D printed models in the surgery of tuberculum sellae meningioma. It can also help pharmacy students with an alternative learning activity in understanding drag-target interaction (Hall, et al. 2017). In dental laboratories, the use of 3D printing has a big impact (Acharya, et al. 2023). These authors suggested that dental technicians preferred 3D printing techniques over traditional hands-on training.

Through the literature search on 3D printed models in students' engagement and learning, it was found that there were many studies completed are useful for industries, schools, and universities. This can be in terms of applications, and engagement of this approach to students' learning. However, gaps have been identified in implementing the 3D printing models in a wider space focusing on face-to-face mode vs distant mode students, students' satisfaction and reactions relating to practicing theoretical concepts to industrial applications, becoming independent learners, improving problem solving skills, and motivating learning that to connect their interest, aspirations, and curiosity. The research question of this study is to quantify the students' reactions to the 3D printing model to enhance their learning focusing on satisfaction, improved spatial ability, and independent learning. Ford and Minshall (2019) pointed out that the implementation of 3D printing practices remained immature. Therefore, this is a good area for further study.

Development of the 3D printed models

The development of the idea of using physical models/3D printed models came as a surprise. The 3D printing model development concept started to evolve in 2009 when an actual physical component of an insulated rail joint (IRJ) (Figure 1) was introduced to a Structural Mechanics

lecture (ENEM12009). The explanation of the suitable material of the endpost and the reasons why it was selected by engineers as the useful material for these joints in railway track structures were given. Due to the students' feedback on this physical "model" and their obvious learning, many models (Figure 2) were collected. The reaction and student feedback on physical models and how they build students' confidence, motivation, engagement and curiosity to grasp complex engineering theories were encouraging (Horowits and Schultz, 2014). It influenced this study. Therefore, the scopes were to develop many 3D printed models (Figure 3) rather than using physical models. It was hard to demonstrate the failure analysis without breaking the physical models, and it was in the deconstruction of the 3D printed versions that enhanced student learning. Figure 3(a) demonstrates the 3D model of the physical model of Figure 2(a), and Figure 3(b) shows the parts when the model fails in a shear mode of failure. In 2014, 3D printed models were employed as a student engagement tool to explain complex mechanical engineering failure analysis concepts. This is impossible with normal physical models (Figure 2(a)) because they cannot be broken apart, but 3D printed models vividly demonstrate to students the key concepts (Figure 3(b)). Since then, many 3D printed models have been prepared and implemented to demonstrate different failure modes by dismantling objects into parts (Figure 3 (b)).

Figure 1: A physical model for student engagement

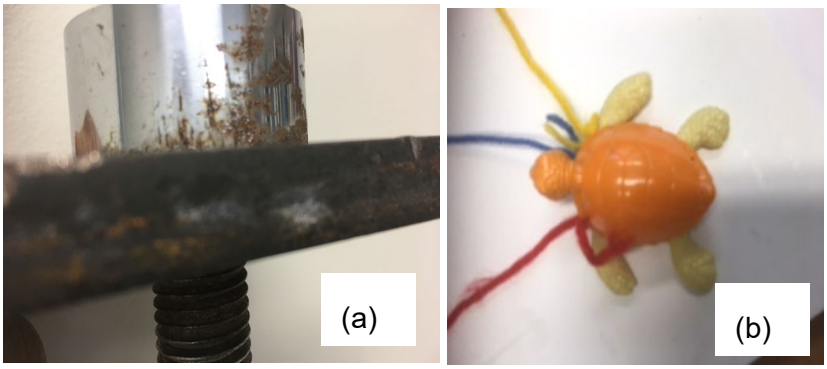

Figure 2: More models for students' engagement: (a) a bracket – a physical model, (b) a turtle – a 3D printed model

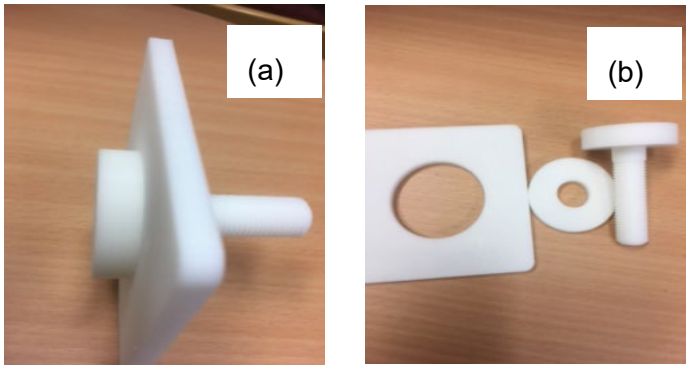

Figure 3: 3D printing models for students: (a) a full model, (b) the model with failure modes

Methodology

The proposed methodology is based on students' reactions to their learning by employing 3D printed model technology relevant to the weekly lecture and tutorial contents and through effective engagement in the teaching approaches. There are a few stages of this method stated in Figure 4.

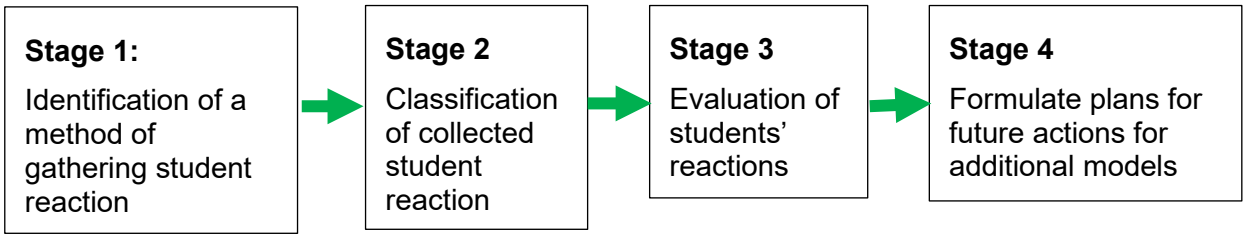

Figure 4: A new student engagement framework for better L&T practices to enhance student learning

Stage 1: Gathering students' reaction – Through the online evaluations of CQU's Student Experience Survey (SES), unanimous students' reaction was collected. This is non-solicited feedback. In addition to that, solicited student feedback by email, and face-to-face discussion was also collected.

Stage 2: Classification of students' reactions – Students were putting their reactions in various directions of 3D printing models. The representative reactions were compiled and classified to identify the nature of reactions and feedback.

Stage 3: Evaluation – By careful reviewing and evaluation of all the students' reactions, a few general directions of students' reactions are considered such as: spatial ability, independent learning, etc.

Stage 4: Future plan of action – As student learning is important, a few action plans are formulated for future offerings so as to close the loop of student feedback.

Student satisfaction data from different years are plotted to see the impact of 3D printing models. Yearly students' reaction is presented in a tabulated form to see the theme of the reactions and the dimension of the reaction.

Student and staff reactions

Student engagement and learning in different disciplines are important. It has many advantages such as: enhancing student learning, developing content and students' problem-solving skills, inspiring students, creativity, creative thinking, interest, and curiosity for learning. As 3D printing models are considered students' confidence building tools, while they are using them, they acquire knowledge and share it with others instead of using 2D 'dry information' out of textbooks as they are engaging in classes with 3D printing models, the students are providing reactions and feedback at the end of the term through the SES system. Table 1 presents these reactions for different recent years with identified feedback dimensions.

Table 1: students' reactions to the Structural Mechanics unit between 2014-2023

Years	Students' reaction	Dimensions of students' reaction	Comments
2014	*I have really enjoyed your examples and use of 3D models to demonstrate the concepts. As a high school physics teacher, I borrowed your turtle*	The application of 3D models to explain the theory of Mechanics	Improved theoretical concept.

	demonstration to teach my year 11s about resultant and vector resolution and they really enjoyed it and found it easy to understand the concept.		
2014	*By using a simple steel ruler, he was able to help me understand shear and torsional forces easily and clearly*	The impact of the 3D printing/physical model's learning and teaching strategy	Impact of physical models.
2015	*The simple ability to rotate a physical object can often bring new elements into view for evaluation that would not be detectable using other methods*	The impact of the 3D printing/physical model's learning and teaching strategy	Impact of physical models.
2019	*The 3D models helped me determine the vital components that are somewhat confusing in 2D dimensions (textbook problems etc.) […] the problem associated with the 3D printing models was easier to understand as the important points/area, etc. can be shown easily*	To inspire mechanical engineering students with their learning and thinking with a wider view in 3D for failure analysis and design of structural members under axial, bending and torsional loadings, not just imagining the phenomena.	Impact of 3D models on the theoretical concept.
2019	*The 3D printed models used to show the stress on the bolts and the possible failure points really helped me showing the effects and failure points possible in real life scenarios. It made the visualisation much easier than just showing pictures during the usual lecture slides and dry information from the textbooks*	The 3D printed models improve the failure analysis of structures under loadings	Impact of 3D models on the theoretical concept.
2019	*I found your sessions are very useful to learn. I can apply my skills to other problems to solve them independently […]. I genuinely enjoy and learn with the way you taught this term*	With the help of the 3D printed models' wider views, students can draw useful diagrams of the loaded bodies accurately and can complete the failure analysis steps independently; students are becoming independent learners.	becoming independent learners
2020	*The inclusion of the 3D printed models was very clever and helped to illustrate how different components deflect or fail*	It improves the failure theory and analysis	Improved problem solving skills.
2023	*3D models really helped me to visualise the problems and to see how material failure can occur in different ways*	It improves the failure theory and analysis	Improved problem solving skills.
2023	*The models are useful for increasing my understanding of what is happening in a particular mechanics problem. They do*	Leverage of 3D printing over 2D textbook demonstrations	Improved problem solving skills.

	this in ways that a textbook diagram can't.		

It is worth presenting the reaction from the academic staff of CQU. Table 2 presents the related feedback on 3D printing for students learning.

Table 2: Feedback on 3D printed models given by academic staff and CQU.

Years	Staff/CQU feedback	Dimension of the feedback	Comments
2016	*All the students from all other campuses have been delighted with this fantastic and effective way of delivery. They are […] engaged with your barrier-less teaching environment and simplicity of presentations. Students developed problem solving skills of complex mechanical engineering concepts*	Development of tensile and compressive stresses in loaded members and fundamental concepts of forces and force components useful for analysis and design.	Development of the theoretical concept of Solid Mechanics
2018	*These 3D models clearly enhanced mechanical engineering student learning even in complex concepts. Dr. Mandal's outstanding L&T practices not only influence his teaching teams but also other colleagues […]"*	Impact on learning complex concept	It supports leadership
2019	*You have provided leadership to affect systematic change and continual improvement across CQUni*	The impact of the 3D printing learning and teaching strategy at the CQU level	The greater impact at the university level

Figure 5, on the other hand away from tabulated students' reactions, presents students' satisfaction (Figure 5a) on a 5.0-point Likert scale along with feedback rate (Figure 5b) and student numbers (Figure 5c). The performance of the unit is quite satisfactory as the student satisfaction score on the 5-point Likert scale is near or over 4.0 for different years with a good feedback rate over the corporate target of 50%. The student satisfaction score of 4.0/5.0 proves the teaching approach is very good and can be continued. If it is low (in 2015, Figure 5a), additional measures can be incorporated into the teaching methods. Figure 5c shows the number of students in different years; using the feedback rate, the number of students who took part in the SES can be calculated. The distributions of high distinction (HD) and distinction (D) rates with low failure (F) rates can add interesting points to the usefulness of the 3D printed models in the unit (Figure 6). In recent years, students' satisfaction rating on the Likert scale has changed to a % rating where 80% or more is an indication of a good unit. This unit has an over 85% rating in 2021 and 2022.

Improving the student attrition rate (lowering the failure rate) (Figure 6) is challenging. The following points can be considered to improve it:

1. Attending and participating in weekly lecture and tutorial sessions
2. Listening to the recording lecture and tutorial recordings
3. Practicing the resource questions regularly
4. Improving the time management skills

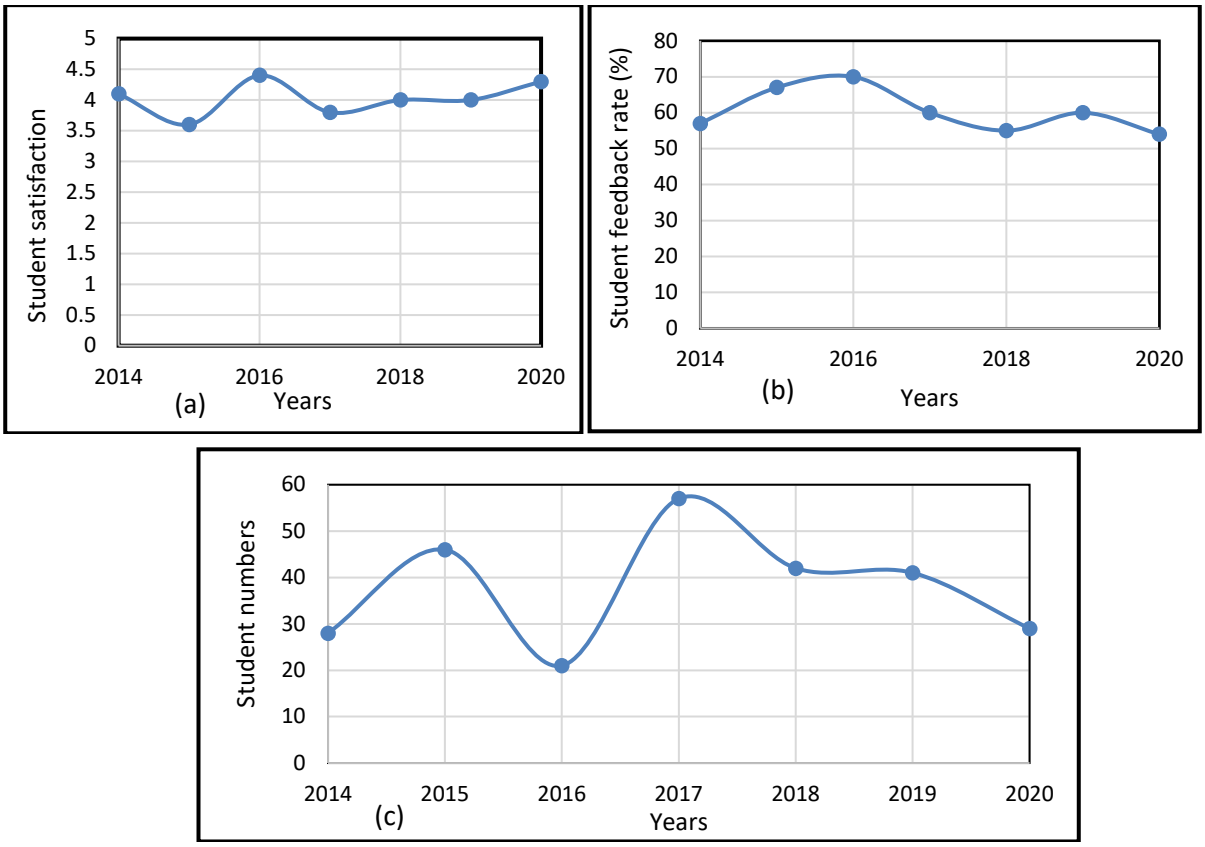

Figure 5: Student evaluation: (a) students' satisfaction, (b) feedback rate, (c) student numbers

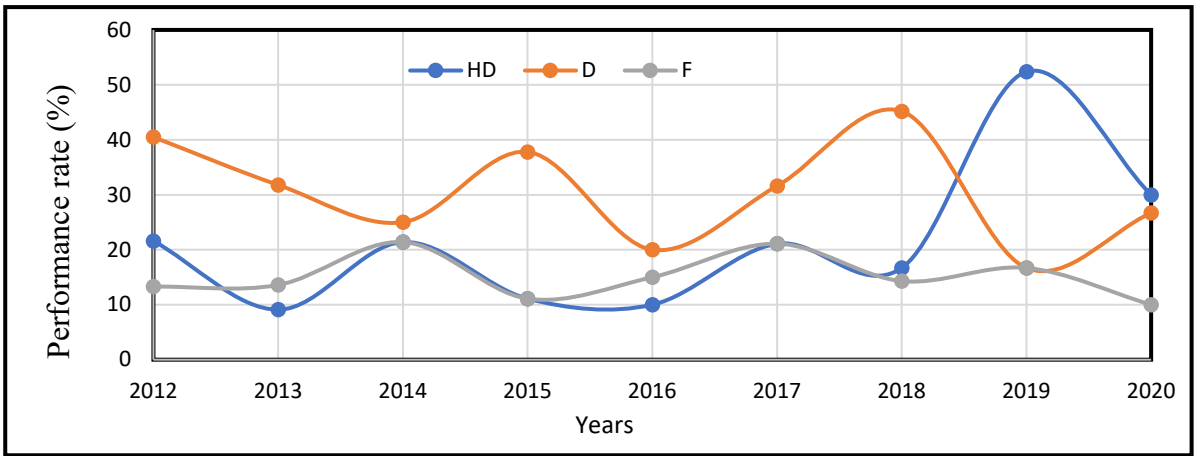

Figure 6: Performance rating (%) of student learning

Conclusions

Gathering students' reactions, and evaluating them for several years from 2014, the following conclusions can be made:

1. The 3D printing models can enhance student learning and problem-solving skills.
2. It can improve students' theoretical concepts and failure analysis of the Solid Mechanics unit.
3. It creates students' motivation, interest, and curiosity in learning.
4. It turns the students into independent learners.
5. This approach can be useful to other disciplines for student learning.

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