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Principles and practices of modular course design in higher engineering education

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Abstract

Purpose – Few resources exist to incorporate principles of modular approach to course design. This research aimed to help instructors by presenting principles for practical and empirically informed modular course design in engineering education.

Design/methodology/approach – In the first phase, a systematic literature review was completed to identify categories addressing a modular course design. Search and screening procedures resulted in 33 qualifying articles describing the development of a modular course. In the second phase, 6 expert interviews were conducted to elaborate on the identified categories.

Findings – Guided by the interview results and the ADDIE (Analyze, Design, Develop, Implement, and Evaluate) course design model, the categories were compiled into six design principles. To present the design principles in relation to the guiding principles of modular approach, an overarching conceptual model was developed.

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Please find enclosed our research article, authored by Dr Canan Mesutoglu, Dr Saskia Stollman and Prof. Dr Ines Lopez Arteaga. We confirm that this research article has not been published elsewhere and is not under consideration by another journal.

The authors have approved the manuscript and agreed with its submission to *International Journal of Information and Learning Technology*. The publication of this research can help the results reach teachers and researchers, with the recognition that the journal encourages research and practice efforts to improve engineering education.

Ethical statement: The authors confirm that this research article has not been published elsewhere and is not under consideration by another journal.

Data availability: Raw data were generated at Eindhoven University of Technology and kept in a folder provided by the same institution. Data can be shared upon request from the corresponding author; CM. Approval from the university ethics committee was obtained prior to data collection. All participants individually filled in informed consent forms.

Declaration of interest statement: The authors declare that they have no competing interests. The authors are willing to address any additional comments on the manuscript. The authors have worked collaboratively at all stages of the research and manuscript preparation.

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Originality/value – Here, we present our innovation; a foundation for an evidence-based systematic approach to modular course design. Implications have value for supporting flexibility and autonomy in learning.

Keywords Higher education, Instructional design, Online modules, Engineering education, Literature review

Paper type Research paper

Introduction

Higher education has been going through profound changes given the increased emphasis on information and communication technologies. The changing nature of the workforce suggests engaging students in learning environments that support flexibility of time and place for learning (Hernandez-de-Menendez and Morales-Menendez, 2019; Sarker *et al.*, 2019). In line with these demands, recent vision statements for 21st century engineering education embrace interactive and online learning, responsiveness to different learning styles and teacher role as a facilitator (National Academy of Engineering, 2012). The adjustments in higher engineering education are evident in the growing applications of open-learning such as massive open online courses, flipped learning and modular instruction (Bradshaw *et al.*, 2013; Sivapalan *et al.*, 2016).

Modular instruction suggests a priority for frequent feedback, self-paced learning and individual interests and learning needs (Dejene, 2019; French, 2015; Goldschmid and Goldschmid, 1973).

Although higher engineering education literature include diverse examples of modular courses, methods of course design are inconclusive and not easily applicable for teachers (Cordray *et al.*, 2008; Jahnke, 2023). There is thus a need for design principles systematically tailored to modular courses. Effective modular instruction partly lies in the support given to teachers (Botma *et al.*, 2015; Sadiq and Zamir, 2014). The goal of this study was to assist instructors with evidence-based instructional design principles for modular courses in higher engineering education.

Conceptual framework

Modular approach in education

Modular approaches in higher education date back to the initiation of an elective course system in the late 1800s at Harvard University (Dochy *et al.*, 1989). Since then, modules have been regarded as components of education and training programmes mostly in reference to credit-based curricula; dividing the curriculum into smaller components (French, 2015). In other words, modularization has been primarily associated with concepts such as semesterization, completion of degree programs, credit transfer and student mobility where courses themselves are treated as modules (e.g. Erasmus programs) (Dochy *et al.*, 1989; French, 2015; Pollard *et al.*, 2017).

From a different yet a complementary perspective, there have been efforts toward construction of a single course with modules in engineering education. Acknowledging the lack of an agreed-upon type of modular approach (Goldschmid and Goldschmid, 1973; Li and Pilz, 2017), this study adopted the conceptualization of modular courses by Boahin and Hofman (2014): “packaging of course content, either theory or practical, into shorter, logically self-contained units”. Key features of online course modules include self-pacing, availability at all times and places, flexibility and frequent practice and feedback (Dochy *et al.*, 1989; Li and Pilz, 2017). Such attributes are rooted in multiple educational approaches such as programmed-instruction, learner-centered pedagogies, computer-assisted instruction and humanistic learning (Botma *et al.*, 2015; Dewey, 1986; Malik, 2012).

Developing modular courses
Modules present a structure for the organization of course concepts and practices (Martínez, 2019). In a modular course, students can move through independent and self-contained modules at their own pace (Goldschmid and Goldschmid, 1973; Li and Pilz, 2017). Benefits of student autonomy in selection and completion of course modules include increased academic achievement, motivation and skills development (e.g. Boahin and Hofman, 2014; Cohen *et al.*, 2019; Malik, 2012; Martínez, 2019).

The momentum toward modular courses brings forth teacher preparedness as a critical element. There is an identified need to support teachers in development and implementation of modules (Boahin and Hofman, 2014; Malik, 2012; Membrillo-Hernández *et al.*, 2021; Schulz and Dahale, 1999). Addressing this need, Félix-Herrán *et al.* (2019) implemented a professional training program to support engineering instructors' preparedness for module design and reported: "This new approach involves changes in the roles of educators . . . a transition from lecturing to facilitating. The professor must design learning modules that satisfy the proposed challenge and encourage students to discover in new scenarios". It has also been proposed that module development should be carried out in the context of conceptual frameworks (Donnelly and Fitzmaurice, 2005). Although there are frameworks that can inspire modular course design in other domains such as health care (Botma *et al.*, 2015), no course design model to help engineering instructors at a practical level could be located. Construction of design principles has significance for the long-term adoption of modular approach in engineering education.

Purpose of the study
Purposeful use of digital technologies can bring about self-paced learning experiences (Hernandez-de-Menendez and Morales-Menendez, 2019). Lack of design principles for modular courses led many studies of engineering education to identify and use components without a systematic consideration of the literature (e.g. Jahnke, 2023). When a well-defined scope is not present, teachers might design and deliver courses that fall short on supporting learning. In view of these constrains and the scholarly consensus regarding the necessity to support teachers, this study aimed to synthesize empirically grounded design principles for modular courses.

Method
This study adopted a convergent consensus-seeking process (Botma *et al.*, 2015) made up of two phases to create design principles for modular courses in higher engineering education. Phase 1 included a systematic literature review to get a good overview of important principles in the instructional design of modular courses. In Phase 2, based on Phase 1 findings and expert views, the design principles were constructed.

Phase 1: systematic literature review
Systematic literature reviews are helpful in creating categorizations for an existing body of research (Collins and Fauser, 2005).

Data collection. Searches were conducted in Ebsco, Web of Science, Scopus and Proquest with the keywords: "engineering education," "module(s)," "modular education," "modular instruction," "modular" and "course". All searches were restricted to articles written in English, published in peer-reviewed journals between 2000 and 2021. Studies conducted before 2000 focused mostly on reforms such as credit transfer systems and semesterization depending on their definition of the concept to treat modules as courses. The researchers collaboratively used an Excel file as an analytical to detail each search attempt memo (Vanassche and Kelchtermans, 2015). The removal of duplicates led to 437 articles.

To eliminate articles that did not fall into the scope of this review, two exclusion criteria were used. Accordingly.

(1) 40 studies that did not report a higher engineering education course and

(2) 235 studies that either reported modules as software or device (e.g. protein module, solar module) or discussed modular approach only in their conclusion were excluded.

Applying the exclusion criteria through screening the titles and the abstracts significantly decreased the number of articles to 162. Skimming full texts, 57 articles were selected for the review, that all accounted for three inclusion criteria:

(1) explained modularization of a course,

(2) detailed the structure and content of an online module e.g. learning outcomes, activities, assessment and/or pedagogical criteria and

(3) detailed how modules were created.

Using purposive sampling (Fraenkel *et al.*, 2012), 16 potentially relevant articles published in the journals: "Journal of Engineering Education" and "International Journal of Engineering Education," and using snowballing (Mourão *et al.*, 2020), another set of 7 articles were manually included in accordance with the inclusion and exclusion criteria.

After carefully reading all 73 full texts, again 40 articles were excluded. These articles were not entirely in line with the inclusion criterion, since they focused on creating a module to be used in multiple courses, rather than modularizing an existing course.

Data analysis. Analysis of the articles can be described as content analysis; study of written content to obtain detailed information in response to educational problems (Fraenkel *et al.*, 2012). The first author read each of the 33 articles full text several times as she noted emerging categories and codes. Later in the process, the second author read a random sample of 10 articles, which she coded independently. Both authors discussed over the codes until agreement was reached, then a codebook was iteratively constructed. For each code, frequencies were calculated to find out the relative importance of certain concepts in modularization literature in higher engineering education (Fraenkel *et al.*, 2012). Table 1 illustrates the codebook with frequencies, together with the corresponding articles' references

Categories	Codes and frequencies
1. Course coverage	Modules for selected course topics or learning outcomes, 8
	Modules for all course content, 24
2. Module components	Resources for theory, 21
	Application exercises, 31
	Module goals, 17
3. Module category	Mandatory and sequenced, 19
	Elective, 6
	Self-pacing within module, 21
4. Key strategies in module implementation	Consistent module form, 20
	Alignment to in-class time, 14
	Alignment to overarching project, 5
	Variety in complexity and guidance, 4
5. Evaluation	Graded module tasks, 17
	Student reflections, 17
	Teacher reflections, 9

Source(s): Created by authors

Table 1.
Codebook for phase 1

with the first author. Researchers' online collaboration on Rayyan.ai and construction of an analytical memo contributed to the trustworthiness of the findings.

Phase 2: design principles

Phase 2 consisted of expert interviews to test usefulness and completeness of Phase 1 results. Expert interviews showed the importance of concepts that were not directly taken from the literature and they therefore were added to the design principles.

Data collection. The 6 experts were instructors and teacher supporters at our institution all experienced in modular instruction. Signed informed consent forms were collected from all experts. During the individual interviews conducted online by the first author, field notes were made. The experts were presented with Phase 1 results as they appear in Table 1 and were asked to provide recommendations considering the use of the design principles by course designers and teachers.

Data analysis. The first steps were reading the field notes right after the interviews, and several more times later to gain familiarity with the data. The field notes were then grouped under the relevant design principle. Next, the notes were checked for similarities and later transformed into a summary. This summary showed recommendations raised by at least three experts (Willis, 2015, p. 163).

Together with the codebook, the results provided the basis for construction of the design principles. The next step for Phase 2 was selecting the generic instructional design model, ADDIE, to structure and organize the results into logical design principles. ADDIE uses 5 steps to instructional design (Campbell and Schwier, 2014; Gagné *et al.*, 2005):

(1) analysis: analyze course content and learning outcomes in relation to modules,

(2) design: explore how modules will help achieve the learning outcomes,

(3) development: create content and materials for modules,

(4) implementation: explore implementation in a course utilizing module-specific strategies and

(5) evaluation: determine impacts of the newly designed modular course.

Guided by the ADDIE model and expert interviews, the codebook that emerged in Phase 1 was translated into a set of six design principles shown in Figure 1. During the systematic literature review, researchers' online collaboration and construction of an analytical memo contributed to the trustworthiness of the findings. The researchers constantly debated and discussed during this process until agreement was reached. The design principles were shared with an audience of instructors and teacher supporters for member checking.

The final step for Phase 2 was to present the conceptual background of our design principles. Figure 2 shows the overarching model that was developed for this purpose.

Results

Phase 1: systematic literature review

Course coverage. Selected course content. 8 articles designed online modules according to selected course topics or course learning outcomes (LOs).

All course contents. In the majority, 24 of the articles, all content, all topics or LOs, of the regular course was covered by the modules.

Module components. Resources for theory. In 21 articles, modules included web links, articles, videos, presentations, lecture slides, book chapters, presentations, or audio-based slides drawing on course theory and topics.

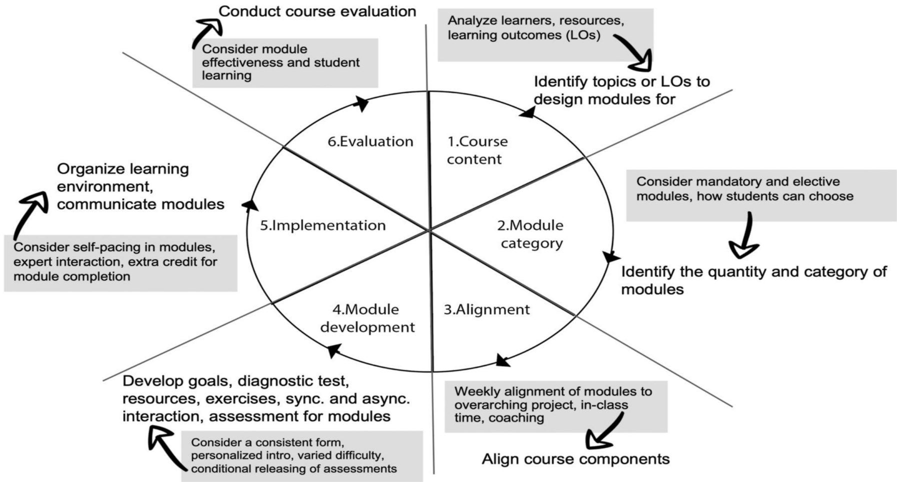

Figure 1.
Design principles

Source(s): Created by authors based on Gagné *et al*. (2005)

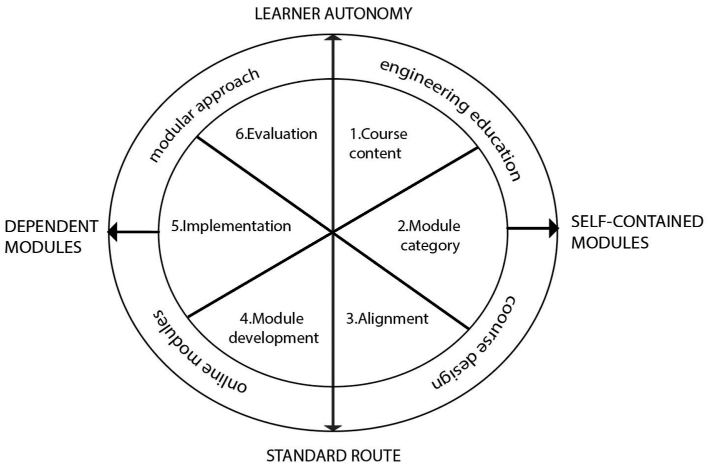

Figure 2.
Conceptual model for modular course design

Source(s): Created by authors

Application. Exercises in the form of games, problem-solving, creating reports and other interactive activities appeared in the modules of 31 articles. The exercises aimed to help students transfer and apply theory. Anderson *et al.* (2005) explained that the module exercises: "interrupt passive learning, which occurs as students read static text or listen to lectures."

A noticeable characteristic of all exercises was their real-world focus. Use of animations and simulations was another frequent attribute. In 2 articles, design problems framed the modules (Chatterjee *et al.*, 2010; Williams *et al.*, 2012). Course instructors' timely feedback and corrective feedback through automated systems were also mentioned ($n = 5$).

Module goals. 17 articles defined separate module LOs or goals. Padmaperuma *et al.* (2006), for example, first identified the content of the modules and then, the course goals were transformed into module goals. Using tables, Martínez (2019) illustrated a systematic alignment of course competencies to subcompetencies developed for each module. Careful formulation of module goals is reported to facilitate student awareness on module components and assessment (n = 5).

Module category. Mandatory and sequenced. A majority of the articles reported that all students were expected to use the modules in a standard route communicated to them.

Elective modules. Six articles developed elective modules. Streif and Naples (2003), for example, presented the students with one mandatory module and for the rest, the students could decide which of the elective modules to use. In a later study Steif and Dollár (2009) students were expected to choose 1 or 2 modules per week, aligned with the weekly assignments, making up at least 9 out of 16 course modules. The articles persistently showed that students' use of elective modules led to improved academic performance. Bernacki *et al.* (2020) and Syed *et al.* (2019) also put forth that, completion of a greater number of elective modules resulted in higher academic performance.

Self-pacing within module. A group of 21 articles reported on students' control over the pace of their progression within the modules, choosing among the module components to interact with (e.g. Altuger-Genc *et al.*, 2018; Henson *et al.*, 2002) or freedom to skip parts (e.g. Pierre *et al.*, 2009). As explained by Khader *et al.* (2017): "The material can be rearranged in different sequences for different learners to match with the learning abilities and preferences . . ." As indicated by Moradi *et al.* (2018), having control over one's own progression within modules resulted in student empowerment. Hailey and Hailey (2019) also evidenced that learning outcomes associated with self-pacing in modules were greater.

Key strategies in module implementation. Although only a few articles specifically mentioned strategies that contributed to student engagement with modules, results could be revealed. Key strategies in module implementation emerged out of specific comments made in the articles, as well as how frequently they occurred, allowing us to use these in our design principles.

Consistent form. A consistent form for modules seems to be important, e.g. module number, title, module aims, prerequisites, outcomes and units for each module.

Alignment to in-class time. If there was face-to-face classroom time alongside the modules, this time was dedicated to lectures, teaching activities and feedback. Most (weekly) in-class time, intended to cover the theoretical course content. As indicated by Altuger-Genc *et al.* (2018), modules: "support the in-class learning as well as to provide students a hands-on and visual animation they can employ to understand the theory better." All articles reported that the students were expected to use the modules before or after the face-to-face sessions.

Alignment to overarching project. In total, five articles described an overarching design project in their courses. The modules served as supportive tools to complete the project. As described by Baughman *et al.* (4): "students apply learning module content tools in completing design project work".

Level of difficulty. Another strategy described in four articles was increasing the level of difficulty, complexity of application exercises and decreasing the amount of teacher guidance as the students progressed within a module or through different modules.

Other key strategies were: using a personalized intro to welcome students (n = 2), assigning extra course credit for module completion (n = 2) and marking module components to release module assessment (n = 1).

Evaluation. To investigate student learning, graded module tasks (n = 17) were in the form of traditional tests/quizzes, interactive exercises, or demonstration of solutions to problems. The courses with an overarching project required a module deliverable with the completion of separate modules, in addition to the final project outputs (e.g. Diefes-Dux *et al.*, 2004).

The articles also reported on collecting data on module use and effectiveness in the form of questionnaires or interviews, 17 studies from students, 9 studies from teachers and 3 articles from stakeholders or experts included in the design and implementation of the course (Habib *et al.*, 2019; Streif and Naples, 2003; Yalvac *et al.*, 2007). Reflections focused on self-paced learning experiences, motivation and perceptions of learning.

Summary. Essential characteristics of modular approach are highlighted in the articles: time and location flexibility, self-paced learning and self-contained modules with multiple components. The results showed that modules can be designed with separate goals, theory, real-world focused practice activities and assessment tasks. Although only a few articles reported on elective modules, results concerning motivation and the learning gains are encouraging.

Phase 2: design principles

The summary of expert interviews evidenced two recommendations: (1) construction of a teacher guide to assist teachers in their design decisions and (2) examination of Phase 1 articles to locate further indications of feedback and online interaction. In the teacher guide, selected articles exemplify, for example, alignment of course LOs to modules, alignment of overarching projects to modules, examples of programming assignments, animations and simulations, courses with elective modules.

Considering further indications of feedback, Moradi *et al.* (2018) is revealed to use a diagnostic test to: "provide a pre-study opportunity for the student so he/she would have a better idea about the content". Khader *et al.* (2017) and Heragu *et al.* (2003) gave module access to external experts, engineers and stakeholders with the goal of providing written feedback and sharing information. To continue, online interaction was offered in modules through synchronous and asynchronous communication; announcements, discussions forums. Henson *et al.* (2002), for example, explained: "questions about class material on the bulletin board where other students, instructor, graduate students and corporate sponsors can asynchronously respond". Video-embedded questions (Moradi *et al.*, 2018) was another indicator.

Summary. Phase 2 produced the design principles (see Figure 1) and the overarching conceptual model (see Figure 2). The conceptual model is built on a modular approach to course design, engineering education literature and the module definition used in this research. The model is structured on two axes. Because each teacher and classroom will necessitate different design decisions, the axes stress the idea of allowing for different modular course designs. As progressing through the course design principles, the axes will also trigger the teacher to constantly reflect on learner autonomy and whether the modules can stand on their own as self-contained modules.

Discussion

In line with practicality, our design principles are simple and inclusive (Yang *et al.*, 2021) and we accompany them with a teacher guide to support the teachers in the design and implementation of the modules (Rota and Izquierdo, 2003).

We are aware the design principles are not necessarily directly applicable to each situation. In the adoption of the design principles, concerning elective modules and programming assignments for example, institutional context needs to be considered. Teachers may face certain limitations like specific equipment and resources (e.g. learning management system, access to programming tools), time constraints and large student numbers (Fan *et al.*, 2021). The design principles should thus be considered as they are meant and that is part of a "constructive and iterative process" as each adoption of new approaches is (Tondeur *et al.*, 2012, p. 141). To facilitate this process, institutional support can be presented in the form of a team directly working with the instructors to be withdrawn gradually (Adamson and Sloan, 2021). The instructors should be encouraged to constantly reflect on their design decisions as they iterate between our principles while at the same time using the teacher guide.

As demonstrated by the horizontal axes of our conceptual model, the design principles support a spectrum ranging from a standard route with "mandatory and sequenced modules" to a high learner autonomy level marked by "all elective modules". The latter can be considered "a radical concept of modularization" with the complete flexibility to follow modules in a mix and match format (Li and Pilz, 2017). As this might not be feasible or necessary for some, our advice would be to start with a few elective modules and let students use modules of their own choice. The rest of the modules agreed upon as foundational by the instructors and an analysis of the students and the resources, can be presented as mandatory. This structure can facilitate students" emerging experiences in adhering to their interest and learning needs by using modules of their choice (Cohen *et al.*, 2019).

Conclusion

To our knowledge, this study is the first attempt to construct empirically grounded design principles for modular courses for engineering education. Next steps include testing the design principles across different course contexts and making modifications based on data gathered from teachers implementing the principles and from students working with the modules. The design principles can benefit from technology-supported instructional design frameworks (e.g. Adamson and Sloan, 2021) and theories such as transactional distance (Stein *et al.*, 2005). In the long run, the validated design principles and the teacher guide are expected to help engineering faculties implement modular courses.

References

Mark with an asterisk* indicate Phase 1 articles.

Adamson, J. and Sloan, D. (2021), "Developing a technology enabled learning framework supporting staff transitioning degree module content to a blended learning approach", *Innovations in Education and Teaching International*, Vol. 60 No. 1, pp. 1-11, doi: 10.1080/14703297.2021.1952642.

* Altuger-Genc, G., Han, Y. and Genc, Y. (2018), "Towards simulation aided online teaching: material design for applied fluid mechanics", *International Journal of Online Engineering*, p. 14.

* Anderson, E.E., Taraban, R. and Sharma, M.P. (2005), "Implementing and assessing computer-based active learning materials in introductory thermodynamics", *International Journal of Engineering Education*, Vol. 21, pp. 1168-1176.

* Bernacki, M.L., Vosicka, L. and Utz, J.C. (2020), "Can a brief, digital skill training intervention help undergraduates 'learn to learn' and improve their STEM achievement?", *Journal of Educational Psychology*, Vol. 112 No. 4, pp. 765-781, doi: 10.1037/edu0000405.

Boahin, P. and Hofman, W.A. (2014), "Perceived effects of competency-based training on the acquisition of professional skills", *International Journal of Educational Development*, Vol. 36, pp. 81-89, doi: 10.1016/j.ijedudev.2013.11.003.

Botma, Y., Van Rensburg, G.H., Coetzee, I.M. and Heyns, T. (2015), "A conceptual framework for educational design at modular level to promote transfer of learning", *Innovations in Education and Teaching International*, Vol. 52 No. 5, pp. 499-509, doi: 10.1080/14703297.2013.866051.

Bradshaw, P., Younie, S. and Jones, S. (2013), "Open education resources and higher education academic practice", *Campus-Wide Information Systems*, Vol. 30 No. 3, pp. 186-193, doi: 10.1108/10650741311330366.

Campbell, K. and Schwier, R.A. (2014), "Major movements in instructional design", in Zawacki-Richter, O. and Anderson, T. (Eds), *Online Distance Education: towards a Research Agenda*, Athabasca University Press, Canada, pp. 345-380.

* Chatterjee, B., Dey, D. and Chakravorti, S. (2010), "A modular approach for teaching partial discharge phenomenon through experiment", *IEEE Transactions on Education*, Vol. 54 No. 3, pp. 410-415, doi: 10.1109/te.2010.2063432.

Cohen, J., Gaul, C., Huprich, J. and Martin, L. (2019), "Design and development of a modular maker education course for diverse education students" in Graziano, K. (Ed.), *Proceedings of Society for Information Technology & Teacher Education International Conference*, pp. 1546-1555.

Collins, J.A. and Fauser, B.C. (2005), "Balancing the strengths of systematic and narrative reviews", *Human Reproduction Update*, Vol. 11 No. 2, pp. 103-104, doi: 10.1093/humupd/dmh058.

Cordray, D.S., Harris, T.R. and Klein, S. (2008), "A research synthesis of the effectiveness, replicability, and generality of the Vanth challenge-based instructional modules in bioengineering", *Journal of Engineering Education*, Vol. 98 No. 4, pp. 335-348, doi: 10.1002/j.2168-9830.2009.tb01031.x.

Dejene, W. (2019), "The Practice of modularized curriculum in higher education institution: active learning and continuous assessment in focus", *Cogent Education*, Vol. 6 No. 1, doi: 10.1080/2331186X.2019.1611052.

Dewey, J. (1986), *Experience and Education*, Kappa Delta Pi, New York, NY.

* Diefes-Dux, H.A., Samant, C., Johnson, T.E. and O'Connor, D. (2004), "Kirkpatrick's Level 1 evaluation of the implementation of a computer-aided process design tool in a senior-level engineering course", *Journal of Engineering Education*, Vol. 93 No. 4, pp. 321-331, doi: 10.1002/j.2168-9830.2004.tb00821.x.

Dochy, F.J.R.C., Wagemans, L.J.J.M. and de Wolf, H.C. (1989), *Modularization and Student Learning in Modular Instruction in Relation with Prior Knowledge*, Centre for Educational Technological Innovation, Heerlen.

Donnelly, R. and Fitzmaurice, M. (2005), "Designing modules for learning", in O'Neill, G., Moore, S. and McMullin, B. (Eds), *Emerging Issues in the Practice of University Learning and Teaching*, AISHE, Dublin, pp. 99-110.

Fan, S.C., Yu, K.C. and Lin, K.Y. (2021), "A framework for implementing an engineering-focused STEM curriculum", *International Journal of Science and Mathematics Education*, Vol. 19 No. 8, pp. 1523-1541, doi: 10.1007/s10763-020-10129-y.

Félix-Herrán, L.C., Rendon-Nava, A.E. and Nieto Jalil, J.M. (2019), "Challenge-based learning: an I-semester for experiential learning in mechatronics engineering", *International Journal on Interactive Design and Manufacturing*, Vol. 13 No. 4, pp. 1367-1383, doi: 10.1007/s12008-019-00602-6.

Fraenkel, J.R., Wallen, N.E. and Hyun, H.H. (2012), *How to Design and Evaluate Research in Education*, McGraw Hill.

French, S. (2015), *The Benefits and Challenges of Modular Higher Education Curricula*, Melbourne Centre for the Study of Higher Education, Melbourne.

Gagné, R.M., Wager, W.W., Golas, K.C. and Keller, J.M. (2005), *Principles of Instructional Design*, Thomson Wadsworth.

Goldschmid, B. and Goldschmid, M.L. (1973), "Modular instruction in higher education: a review", *Higher Education*, Vol. 2 No. 1, pp. 15-32, doi: 10.1007/bf00162534.

* Habib, E., Deshotel, M., Lai, G. and Miller, R. (2019), "Student perceptions of an active learning module to enhance data and modelling skills in undergraduate water resources engineering education", *The International Journal of Engineering Education*, Vol. 35, pp. 1353-1365.

* Hailey, C.E. and Hailey, D.E. (2019), "Evaluation of instructional design of computer-based teaching modules for a manufacturing processes laboratory", *Journal of Engineering Education*, Vol. 89 No. 3, pp. 345-352, 10.1002/j.2168-9830.2000.tb00535.x.

* Henson, A.B., Fridley, K.J., Pollock, D.G. and Brahler, C.J. (2002), “Efficacy of interactive internet-based education in structural timber design”, *Journal of Engineering Education*, Vol. 91 No. 4, pp. 371-378, doi: 10.1002/j.2168-9830.2002.tb00719.x.

* Heragu, S.S., Graves, R.J., Malmborg, C.J., Jennings, S. and Newman, D.L. (2003), “Multimedia tools for use in materials handling classes”, *European Journal of Engineering Education*, Vol. 28 No. 3, pp. 375-393, doi: 10.1080/0304379031000098292.

Hernandez-de-Menendez, M. and Morales-Menendez, R. (2019), “Technological innovations and practices in engineering education: a review”, *International Journal on Interactive Design and Manufacturing (IJIDeM)*, Vol. 13 No. 2, pp. 713-728, doi: 10.1007/s12008-019-00550-1.

Jahnke, I. (2023), “Quality of digital learning experiences–effective, efficient, and appealing designs?”, *The International Journal of Information and Learning Technology*, Vol. 40 No. 1, pp. 17-30, doi: 10.1108/ijilt-05-2022-0105.

* Khader, A.A., Brahadeeswaran, D. and Poongavanam, S. (2017), “Development of knowledge based on tutoring system of engineering drawing”, *Journal of Economic and Management Perspectives*, Vol. 11, pp. 1691-1697.

Li, J. and Pilz, M. (2017), “Modularisation in the German VET system: a study of policy implementation”, *Journal of Education and Work*, Vol. 30 No. 5, pp. 471-485, doi: 10.1080/13639080.2016.1243233.

Malik, S.K. (2012), “Effects of modular and traditional approaches on students’ general comprehension”, *Elixir Social Studies*, Vol. 42, pp. 6228-6231.

* Martínez, R.J.D. (2019), “Design and implementation of a Semester I for mechatronics”, *International Journal on Interactive Design and Manufacturing (IJIDeM)*, Vol. 13 No. 4, pp. 1441-1455, doi: 10.1007/s12008-019-00604-4.

Membrillo-Hernández, J., de Jesús Ramírez-Cadena, M., Ramírez-Medrano, A., García-Castelán, R.M. and García-García, R. (2021), “Implementation of the challenge-based learning approach in academic engineering programs”, *International Journal on Interactive Design and Manufacturing (IJIDeM)*, Vol. 15 Nos 2-3, pp. 287-298, doi: 10.1007/s12008-021-00755-3.

* Moradi, M., Liu, L., Luchies, C., Patterson, M.M. and Darban, B. (2018), “Enhancing teaching-learning effectiveness by creating online interactive instructional modules for fundamental concepts of physics and mathematics”, *Education Sciences*, Vol. 8 No. 3, p. 109, doi: 10.3390/educsci8030109.

Mourão, E., Pimentel, J.F., Murta, L., Kalinowski, M., Mendes, E. and Wohlin, C. (2020), “On the performance of hybrid search strategies for systematic literature reviews in software engineering”, *Information and Software Technology*, Vol. 123, 106294, doi: 10.1016/j.infsof.2020.106294.

National Academy of Engineering (2012), *Understanding the Educational and Career Pathways of Engineers*, The National Academies Press, Washington, DC.

* Padmaperuma, G.A., Ilanko, S.I.N.N.I.A.H. and Chen, D. (2006), “Opportunities and Challenges in instructional design for teaching the flexure formula using the revised Bloom’s Taxonomy”, *International Journal of Engineering Education*, Vol. 22, p. 148.

* Pierre, J.W., Tuffner, F.K., Anderson, J.R., Whitman, D.L.A.S., Ula, A.H.M.S., Kubichek, R.F., Wright, C.H.G., Barrett, S.F., Cupal, J.J. and Hamann, J.C. (2009), “A one-credit hands-on introductory course in electrical and computer engineering using a variety of topic modules”, *IEEE Transactions on Education*, Vol. 52 No. 2, pp. 263-272, doi: 10.1109/te.2008.928185.

Pollard, E., Hadjivassiliou, K., Swift, S. and Green, M. (2017), *Credit Transfer in Higher Education: A Review of the Literature*, Department for Education.

Rota, G. and Izquierdo, J. (2003), “Comics as a tool for teaching biotechnology in primary schools”, *Electronic Journal of Biotechnology*, Vol. 6 No. 2, pp. 85-89, doi: 10.2225/vol6-issue2-fulltext-10.

Sadiq, S. and Zamir, S. (2014), “Effectiveness of modular approach in teaching at university level”, *Journal of Education and Practice*, Vol. 5, pp. 103-109.

Sarker, M.N.I., Wu, M., Cao, Q., Alam, G.M. and Li, D. (2019), "Leveraging digital technology for better learning and education: a systematic literature review", *International Journal of Information and Education Technology*, Vol. 9 No. 7, pp. 453-461, doi: 10.18178/ijiet.2019.9.7.1246.

Schulz, K.C. and Dahale, V. (1999), "Multimedia modules for enhancing technical laboratory sessions", *Campus-Wide Information Systems*, Vol. 16 No. 3, pp. 81-95, doi: 10.1108/10650749910281241.

Sivapalan, S., Clifford, M.J. and Speight, S. (2016), "Engineering education for sustainable development: using online learning to support the new paradigms", *Australasian Journal of Engineering Education*, Vol. 21 No. 2, pp. 61-73, doi: 10.1080/22054952.2017.1307592.

* Steif, P.S. and Dollár, A. (2009), "Study of usage patterns and learning gains in a web-based interactive static course", *Journal of Engineering Education*, Vol. 98 No. 4, pp. 321-333, doi: 10.1002/j.2168-9830.2009.tb01030.x.

Stein, D.S., Wanstreet, C.E., Calvin, J., Overtoom, C. and Wheaton, J.E. (2005), "Bridging the transactional distance gap in online learning environments", *The American Journal of Distance Education*, Vol. 19 No. 2, pp. 105-118, doi: 10.1207/s15389286ajde1902_4.

* Streif, P.S. and Naples, L.M. (2003), "Design and evaluation of problem-solving courseware modules for mechanics of materials", *Journal of Engineering Education*, Vol. 92 No. 3, pp. 239-247, doi: 10.1002/j.2168-9830.2003.tb00764.x.

* Syed, Z.A., Trabookis, Z., Bertrand, J., Madathil, K.C., Hartley, R.S., Frady, K.K., Wagner, J.R. and Gramopadhye, A.K. (2019), "Evaluation of virtual reality-based learning materials as a supplement to the undergraduate mechanical engineering laboratory experience", *International Journal of Engineering Education*, Vol. 35, pp. 1-11.

Tondeur, J., Van Braak, J., Sang, G., Voogt, J., Fisser, P. and Ottenbreit-Leftwich, A. (2012), "Preparing pre-service teachers to integrate technology in education: a synthesis of qualitative evidence", *Computers and Education*, Vol. 59 No. 1, pp. 134-144, doi: 10.1016/j.compedu.2011.10.009.

Vanassche, E. and Kelchtermans, G. (2015), "The state of the art in self-study of teacher education practices: a systematic literature review", *Journal of Curriculum Studies*, Vol. 47 No. 4, pp. 508-528, doi: 10.1080/00220272.2014.995712.

* Williams, R.R., Gardner, S.K., Limberis, L. and Sullivan, S.T. (2012), "The implementation of a challenge-based curriculum into a bioprocess engineering program", *The International Journal of Engineering Education*, Vol. 28, pp. 1150-1160.

Willis, G.B. (2015), *Analysis of the Cognitive Interview in Questionnaire Design*, Oxford University Press.

* Yalvac, B., Smith, H.D., Troy, J.B. and Hirsch, P. (2007), "Promoting Advanced writing skills in an upper-level engineering class", *Journal of Engineering Education*, Vol. 96 No. 2, pp. 117-128, doi: 10.1002/j.2168-9830.2007.tb00922.x.

Yang, K.L., Tso, T.Y., Chen, C.S., Lin, Y.H., Liu, S.T., Lin, S.W. and Lei, K.H. (2021), "Towards a conceptual framework for understanding and developing mathematical competence: a multi-dual perspective", *Innovations in Education and Teaching International*, Vol. 58 No. 1, pp. 72-83, doi: 10.1080/14703297.2019.1687317.

Further reading

* Baughman, J., Hassall, L. and Xu, X. (2019), "Comparison of student team dynamics between non-flipped and flipped versions of a large-enrolment sophomore design engineering course", *Journal of Engineering Education*, Vol. 108 No. 1, pp. 103-118, doi: 10.1002/jee.20251.

* Bhandari, A., Ong, S.K. and Steward, B.B. (2011), "Student learning in a multidisciplinary sustainable engineering course", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 137 No. 2, pp. 86-93, doi: 10.1061/(asce)ei.1943-5541.0000055.

* Chang, J.P. (2002), "A new undergraduate semiconductor manufacturing option in the chemical engineering curriculum", *International Journal of Engineering Education*, Vol. 18, pp. 369-378.

* Cummings, M.L. (2006), "Conducting online course dialogue on the ethics of weapons design", *IEEE Technology and Society Magazine*, Vol. 25 No. 1, pp. 31-37, doi: 10.1109/mtas.2006.1607722.

* Deliktas, B. (2011), "Computer technology for enhancing teaching and learning modules of engineering mechanics", *Computer Applications in Engineering Education*, Vol. 19 No. 3, pp. 421-432, doi: 10.1002/cae.20321.

* Downey, G.L., Lucena, J.C., Moskal, B.M., Parkhurst, R., Bigley, T., Hays, C., Jesiek, B.K., Kelly, L., Miller, J., Ruff, S., Lehr, J.L. and Nichols-Belo, A. (2006), "The globally competent engineer: working effectively with people who define problems differently", *Journal of Engineering Education*, Vol. 95 No. 2, pp. 107-122, doi: 10.1002/j.2168-9830.2006.tb00883.x.

* Geller, J., Carpenter, S.K., Lamm, M.H., Rahman, S., Armstrong, P.I. and Coffman, C.R. (2017), "Pre-questions do not enhance the benefits of retrieval in a STEM classroom", *Cognitive Research: Principles and Implications*, Vol. 2, pp. 1-13, doi: 10.1186/s41235-017-0078-z.

* Jenkins, H. and Burtner, J. (2007), "An approach to develop and measure engineering visualization in an introductory mechanics course using computer-aided learning modules", *International Journal of Engineering Education*, Vol. 23, pp. 150-161.

* Kaw, A.K., Besterfield, G.H. and Eison, J. (2005), "Assessment of a web-enhanced course in numerical methods", *International Journal of Engineering Education*, Vol. 21, pp. 712-722.

* Lux, J.R. and Davidson, B.D. (2003), "Guidelines for the development of computer-based instruction modules for science and engineering", *Journal of Educational Technology and Society*, Vol. 6, pp. 125-133.

* Nair, I., Jones, S. and White, J. (2002), "A curriculum to enhance environmental literacy", *Journal of Engineering Education*, Vol. 91 No. 1, pp. 57-67, doi: 10.1002/j.2168-9830.2002.tb00673.x.

* Pimmel, R.L. (2003), "Student learning of Criterion 3 (A)-(K) outcomes with short instructional modules and the relationship to Bloom's Taxonomy", *Journal of Engineering Education*, Vol. 92 No. 4, pp. 351-359, doi: 10.1002/j.2168-9830.2003.tb00780.x.

* Siddique, Z., Ling, C., Roberson, P., Xu, Y. and Geng, X. (2013), "Facilitating higher-order learning through computer games", *Journal of Mechanical Design*, Vol. 135 No. 12, doi: 10.1115/1.4025291.

* Stern, F., Xing, T., Yarbrough, D.B., Rothmayer, A., Rajagopalan, G., Prakashotta, S., Caughey, D., Bhaskaran, R., Smith, S., Hutchings, B. and Moeykens, S. (2006), "Hands-on CFD educational interface for engineering courses and laboratories", *Journal of Engineering Education*, Vol. 95 No. 1, pp. 63-83, doi: 10.1002/j.2168-9830.2006.tb00878.x.

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