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An assessment framework for creative production in computing and engineering disciplines

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ABSTRACT

With the increasing expansion of creative computing courses among higher education institutions, there is a growing demand for more objective and efficient assessment frameworks that cater to the multidisciplinary skills that students engage in during the production of such work. This research addresses persistent gaps for a systematic approach of assessing creative content in technical courses. Existing theories are reviewed including creative requirements framework and computing production model, which leads to the establishment of a newly proposed assessment framework. A mixture of research methods is employed combining both inductive and deductive approaches, evidence- based analysis, and case study, based on data collected over three academic years at a British university. The proposed assessment framework incorporates three factors of production (function, usability, and management) and two attributes of creativity (core and optional requirements), which is evaluated to determine its suitability for accurately reflecting the work undertaken by students. Creativity is quantified in the assessment based on technical contribution. The proposed framework can be applied in the delivery of courses involving creative production in the computer science and engineering disciplines in which teaching usually focuses on technical content rather than contextual design, creativity, or aesthetics. The findings reveal positive feedback and a number of pertinent outcomes, including promoting creativity, student satisfaction, and efficient assessments. The framework may be adopted by educators for similar courses that are underpinned by technical skills and creativity.

1. Introduction

Degrees and vocational courses in the area of creative computing have become increasingly popular across higher education institutions. The discipline combines talents in technical subjects (mostly computer science and electronic engineering) with artistic production, leading to the creation of digital media content and artefacts which typically manifest in the form of web media, interactive games, mobile apps, and digital music. Such artefacts also possess common attributes, including facilities for user interactions, multimedia modality, and elements of visual impact. Consequently, the study and creation of such creative products not only necessitates an understanding and command of art and design subjects, but also knowledge and ability in computer science and engineering disciplines. The rationale of this research therefore originates from the challenges of teaching and assessing creative subjects within the science and technology discipline. This study aims to address these challenges via the following five objectives:

(1) Identify gaps and challenges in creative computing assessment, and determine key contributing factors for a new assessment framework based on existing foundational theories.
(2) Formulate assessment components for students' achievements whilst minimizing the use of subjective judgements, which can be used efficiently for large student cohorts.
(3) Explore how the assessment framework can integrate both technical and creative elements of student work in the domain of creative computing such as mobile app production.
(4) Quantify the assessment of creativity from technical perspective whilst promoting students' engagement with creativity.
(5) Reflect on the efficacy of the proposed assessment framework based on pedagogic practice and teaching observations via a case study.

The nature of the creative computing process may often involve user psychology and marketing as well in order more fully to understand

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audiences and what they expect from resulting artefacts. Creativity is not specific to any domains and should be assessed by products [1]. Unsurprisingly, creative computing is largely regarded as a software process [2], whereby the teaching process will likely encompass software engineering subjects if the intention is to deliver a functional product implemented via programming and testing principles. Within this context, the study of creative computing subjects within this technical foundation will often lead to difficulties in applying established pedagogies, especially from the design and creative standpoint. The teaching and assessment of this subject therefore faces many challenges, and the success of traditional well-established pedagogies for technical subjects often cannot be easily mapped to the field of creative production, in which assessments of student work typically involve subjective judgements of creative artefacts for components such as the extent of interactivity, visual appeal, and overall satisfaction. This article will propose solutions to these aspects.

More broadly, there can be several other notable challenges during course delivery. First, students in science and engineering disciplines usually possess technical competencies or at least have fervent interest in developing skills in the area. However, creative and design skills may not be within their remit, areas of which are naturally catered for in art and design disciplines. Be that as it may, it is patently important that the creative digital artefacts necessitate technical, design, and creative competences. This nuance will be reflected in the model proposed below. Second, the delivery of technical content on subjects such as mathematics, programming, and associated principles can often be labelled as "boring" [3], which in turn affects students' motivation and interest in the field. The role of teaching in this area therefore increases the demand for multidisciplinary expertise and the ability to promote students' intellectual stimulation so as to deliver enjoyable learning content that emphases technical skills as well as creative faculties. Third, a challenge is also present during the assessment stage as grading creative outputs may often lead to subjective comments. These can transpire remarks from assessors that may take the form of: "I liked the product", "The app was very appealing", and "The experience was fun and enjoyable". While such feedback may well be pertinent to student work, they could also result in challenges from students about their grading since comments such as these are invariably based on subjective judgement. Fourth, assessments are often perceived to have restricted student creativity during the teaching and learning process [4], and there is a gap for a systematic assessment framework that can promote or maintain creativity whilst delivering effectiveness. Lastly, there is a relative shortage of theoretical approaches to support the teaching and practice pertaining to the nuanced requirements in creative production. For instance, the subject of usability is usually a popular and important subject in courses involving creative and digital media, yet most usability frameworks were designed in the era of traditional desktop computing and may lack direct relevance to more recent mobile and other emerging technologies. The current ubiquitous computing phenomenon involves the Internet of Things, big data, cloud computing, and other emerging technologies, which themselves often link to mobile computing environments. There are hence salient research gaps in the modernization of techniques for conducting user requirements and usability analyses in the context of these new forms of technology and user engagement.

The ideas and outcomes presented in this research are based on actual pedagogic practice and teaching observations in the delivery of a creative computing production module spanning a total of three individual academic years. In the culmination of each year, students are tasked to design and produce a mobile application as the final artefact to be submitted for assessment. This article therefore emphasizes the requirements placed on the design and use of assets (such as images and animations) for app production, as will be documented in detail below. This therefore extends beyond merely achieving technical outputs by appreciating the need for students to engage with the aesthetic challenges and demands in creative forms of production.

In the following, Section 2 reviews existing work in the field and summarises available theoretical evidence that can be used to support the proposed assessment framework. Section 3 explains the designated methodology applied in this investigation while Section 4.1 elaborates on the details of the proposed assessment framework. Section 5 highlights the quantification technique for assessing creativity. Section 6 demonstrates the overall outcomes that may be expected from applying the proposed teaching paradigm by analysing results from student performance and feedback across the three years of course delivery. Section 7 offers the final conclusions, reflections of strengths and limitations, as well as suggestions for further work.

2. Theoretical foundations

2.1. Existing work

There have been ample studies on the subject of learning and assessment, a selection of which is shown in Table 1. A range of the literatures focus on learner-centred approaches: early work by [5] analyses the role of learners' behaviours in formulating an effective assessment framework while [9] surveys matters concerning student wellbeing in the assessment context [7] investigates the more specific contribution of effective assessments towards building positive graduate attributes in higher education. Some researchers have also used specific case studies on design and development, such as those by [10–12]. A wide range of work have also explored the use of technologies to enhance and innovate assessment with examples including [13–16]. In terms of academic quality and standards for assessing students' work, considerably effort has been placed on proposing measurements in grading students' achievements, for example in the form of benchmarking and standardisation [17], quality assurance[18,19], and marking criteria [20]. Assessment and feedback have been ongoing in terms of research efforts [21,22], while relatively few studies have explored the impact and associations between pedagogy and assessment (examples here include those by [23–25] and [26] who have investigated formative assessment practices).

Table 1 reveals research gaps for assessing creativity in computer science and engineering disciplines:

a. Some existing work have discussed the assessment strategies in science and engineering disciplines but have not covered the creativity element [5,10,11,12,14].
b. Those who have assessed creativity are of education discipline in general and not specific to science and engineering disciplines [28–31,4,32]. Unique characteristics concerning science and engineering students should be addressed, where they specialise in technical development via a range of coding and development techniques. Hence the assessment strategy for creative production in these disciplines demand tailored approach to examine both their technological strength and contextual awareness.
c. It is also worth noting that many existing research have proposed sensible techniques for assessment without testing and validation, and there is a need for a more concrete approach to evaluate the proposed assessment approaches.
d. Work in [33] is considered as the most relevant work to this article, which explores the assessment design of engineering courses that takes creativity into account, however the proposed technique is not fully established as a comprehensive framework, nor has it been tested in real-life practice.

In view of existing bodies of work, there remains a notable research gap within cross-disciplinary teaching and assessment contexts. This article will address this gap by promoting creativity in computing production process, establishing an assessment framework, and validating the feasibility via testing in undergraduate classes of science and engineering discipline. The following discussions will review relevant

Table 1
Existing work in the relevant areas of assessment.

	Learners	Design	Technology	Quality	Feedback	Creativity	Discipline	Framework	Testing
[5]	✓	✓					Mathematics		
[6]	✓				✓		Education		
[7]	✓	✓			✓		Accounting	✓	
[8]	✓	✓			✓		Education		✓
[9]	✓	✓			✓		Healthcare		✓
[10]		✓		✓			Computing	✓	✓
[11]		✓					Computing	✓	
[12]		✓		✓			Computing	✓	Empirical
[13]			✓				Education	✓	✓
[14]	✓		✓		✓		Mathematics	✓	✓
[15]	✓	✓	✓	✓			Education		
[16]	✓	✓	✓				Education		✓
[17]	✓	✓		✓			Education		✓
[18]		✓		✓			Education	✓	✓
[19]				✓			Education		✓
[20]		✓		✓	✓		Education		
[21]					✓		Education	✓	
[22]	✓				✓		Education		
[23]	✓	✓	✓		✓		Education		
[24]	✓	✓		✓	✓		Education		
[25]	✓	✓					Education		
[26]	✓	✓					Education		✓
[27]	✓	✓				✓	Business	✓	
[28]			✓			✓	Education		
[29]	✓	✓				✓	Education	✓	
[30]	✓					✓	Education	✓	
[31]	✓	✓				✓	Education	✓	
[4]						✓	Education		
[32]	✓		✓			✓	Education		✓
[33]		✓				✓	Engineering		

theoretical models with regards to creativity and computing production.

2.2. Theoretical model for creativity

Research in [34] has identified a set of requirements that can be used to prioritise the creative design and implementation, which has been further developed by [33]. The original Kano model differentiates between basic- requirements, performance-requirements, and excitement-requirements, which are namingly the boundary-requirements, important-requirements, and vital- requirements in the Gerst model. Basic-requirements must be fulfilled to have a viable product, which usually do not lead to high user satisfaction as they are strongly expected; however their absence would cause major dissatisfaction. Basic-requirements are usually defined by constraints. Performance- requirements can be expressed by users which reflect the user expectations of the product. Excitement-requirements include features to yield performance beyond user expectation so as to gain high user satisfaction. These features are likely to carry identify-requirements that reflect the theme and design choices from the designer.

Fig. 1 shows an adopted version of the creativity requirements model as mentioned above, which can be used for academic context. The basic-requirements refer to the minimum conditions to pass the course where certain module-specific constrains may apply. Take British universities for instance, the basic requirements to cover all the learning outcomes so as to pass a module is 40%. The performance-requirements include a range of expectations for the given academic discipline. Students who satisfy both basic and performance requirements (namely core-requirements in combination) can gain distinction marks (e.g. 70% in UK). Optional-requirements, as the name suggests, are not mandatory for students to cater in the given discipline.

Students have the freedom to customise the existing features or add new features to deliver outstanding user experience. Aside the core

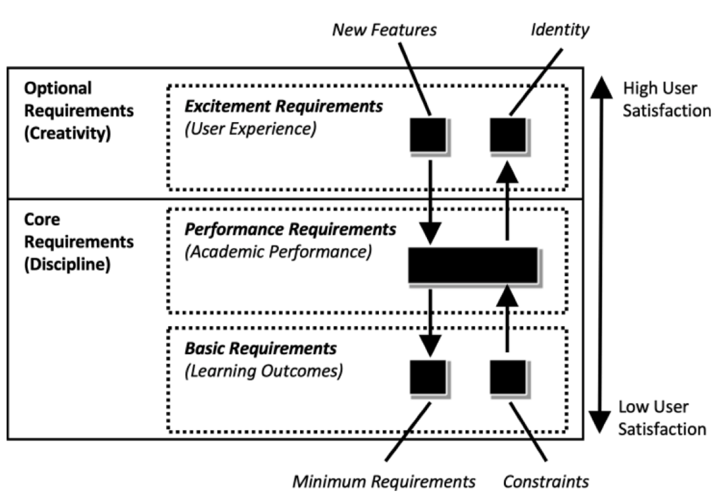


Fig. 1. Creativity requirements model for academic context (adopted and modified from [34,33]).

disciplinary requirements, the optional-requirements leave an open space for creativity which may reflect students' identity and interests.

The rationale behind using core and optional requirements in assessments of university coursework is to ensure that students demonstrate a solid understanding of the course material while also allowing them to personalize their learning experience. Several studies have justified the application of this theory in academic context [35–37]. Core requirements are designed to assess the fundamental concepts and skills that are essential to the course. These elements are mandatory and must be completed by all students. They are used to evaluate the core knowledge that students have gained throughout the course and to determine whether they have met the essential learning requirements. Optional requirements, on the other hand, allow students to explore areas of interest within the course material. These elements are not mandatory, but they provide an opportunity for students to showcase their creativity, critical thinking, and research skills. Optional requirements can also be used to challenge students to think beyond the scope of the course material and to apply their knowledge to real-world scenarios.

The concerns of different domains for creativity have been studied in [1]: if creativity is a domain-general skill such as art and design, then creativity should be reflected on virtually every aspect of the product; creativity is not a domain-general skill for disciplines like the computing and engineering where disciplinary knowledge and skills are much more significant. The Consensual Assessment Technique (CAT), originally developed in 1982 [38], has been widely cited and used in the field of creativity assessment because it is based on evaluations of actual creative performances or artefacts. Many other research have advocated the rationale of CAT and recommended the assessment approach based on creative products such as [39,40]. Therefore, it is vital to consider the production process for creative computing artefacts, which will be discussed in the following section.

2.3. Model of computing production

The production of creative computing artefact is more than an approach of software programming [41], which in fact encompasses compound planning and implementation processes [42]. Learners in computer science and engineering disciplines are often given little opportunity to gain knowledge in topics such as media content, user experience, level design, and visual appearance, due to the inherent technical content of the courses on which they are enrolled. These topics may be commonly known as contextual analysis and visual design, which are not usually covered to any great extent (if at all) in computing and engineering disciplines. Whatever the rationale for any lack of coverage of such content, there is nevertheless a strong correlation between the technical implementation and contextual design – the latter must inevitably be implemented using technical methods that follow contextual designs in order to deliver the intended solution. Common and salient themes in areas of contextual design and user interaction for creative products typically fall into the broad umbrella of 'usability'. As such, various usability models exist to serve this purpose, including those by [43–45]. Among these, the ISO model may be considered as one of the most suitable for modern computing for both desktop and mobile applications [44]. With this in mind, the ISO model was considered here as a guideline for course delivery within creative computing subject areas.

The ISO usability model defines usability as the extent to which a product can be used to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. This model is illustrated in the Appendix A.

In essence, the model presents three factors to be defined: user, goal, and context, and three attributes to be measured: effectiveness, efficiency, and user satisfaction. The "user" factor interacts with the product and may carry certain features, such as age group, gender, education background, and career. "Goal" is the intended outcome, which can be loosely defined as the desired functionalities by users. "Context" refers to the physical and social environments where the product is used and where various questions need to be asked to determine suitable design. As for measuring user experience, "effectiveness" means the success of execution which assesses whether the intended goals are achieved. Finally, "efficiency" is the time to complete a task and "user satisfaction" refers to the users' overall impression of the product. As shown in the model, the "Goal" factor (essentially representing desired functionalities) usually serves as the main area of focus during teaching and learning in science and engineering disciplines since it determines the actual implementation of necessary and functional elements. However, in order for the model to be fully represented beyond functional implementation, the remaining factors and attributes pertaining to the usability model also need be considered as substantial elements in the pedagogy.

In addition to functionality and usability concerns, production management is also a salient aspect of the production process. The significance of project management in the delivery of any product or service has long been an established area of study spanning at least the last four decades with extensive evidence outlined in examples such as [46–48], and [49]. More recently, the Agile project management methodology has been widely adopted as a popular alternative to traditional methods such as the waterfall technique [50]. One prevailing advantage of Agile is that it can be applied effectively in both software and non-software disciplines, regardless of the complexity of the project or the experience within the project team [51], making it highly suitable for managing tasks in multidisciplinary scenarios [52,51] has also shown that the design quality of project goals and tasks proffered in Agile management can significantly impact overall project success, which indicates that enhancing the ability to devise and allocate tasks in a project should be regarded as a valuable learning outcome within the Agile process. Complementing this is that version control methodology is also a crucial component for the documentation of the production process, especially with respect to computing tasks that may involve multiple team members [53]. Version control has been widely used in academic scenarios to enhance learning or monitor student progress [54,55]. In project-based learning scenarios, version control techniques serve as essential tools for aspects such as tracking historical computer code, error recovery, collaborative and social coding, and code storage. Compared to more traditional methods for students to submit completed work, where only the final version is delivered for grading, students' entire development process can be made visible and accessible by instructors through the use of version control techniques. In recent years, well-known version control platforms such as GitHub, CVS, and SVN have served the added purpose of helping to detect unwarranted collusion or even plagiarism of developed software code [56,57], which may otherwise be difficult if not impossible by using more traditional detection tools such as Turnitin or paper repositories. Taken collectively, advantages such as these should be incorporated in the modern teaching and learning of creative production subjects.

Extending from the initial ideas outlined above, upon reviewing existing evidence of previous research, the creative production process can be conceptualised as an intersection of three core factors: Function, Usability, and Management, as summarized in Fig. 2. The combination and extent to which each of the three components are present and working in tandem can be considered a vital ingredient for success. For Function, the adoption and considered use of good practises for software engineering can promote higher-quality and reliable development processes, such as to ensure company resources and development teams are suitably established. In turn, these relate to the need for effective Management approaches for controlling the lifecycle of production using suitable techniques, such as version control (particularly in the case of larger projects and teams) and the use of contemporary techniques such as agile management to allow greater flexibility in the development cycle. Finally, the Usability addresses the fundamental need to ensure the final product meets the needs and expectations of

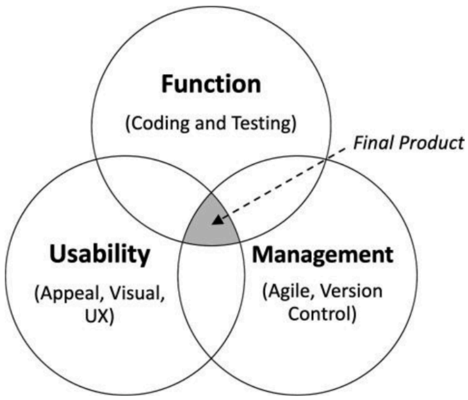


Fig. 2. Contributing factors to computing production.

users, which may manifest in the form of visual design, product appeal and functionality, and a desired level of user experience. Interpretations of the three factors in the context of the proposed assessment structure and case study from Section 3 are explained as follows.

3. Methodology

Established research methodologies were adopted in the study using a mixture of techniques to address the research aim of developing and validating a new proposed assessment framework for creative production in computing and engineering disciplines, including a combination of inductive and deductive research, evidence-based research, and case study.

3.1. Inductive and deductive approach

The inductive approach is a well-established method for requirement engineering [58], which is an ideal choice for exploring and investigating the requirements of establishing an effective assessment framework for this research. Approximately half of the research in the field of computing and engineering is reported to be deductive in nature [59]. This may be explained by the fact that deductive methods of investigation are generally considered as an established scientific way of sourcing and verifying knowledge, especially when programming and development work is concerned [60], which tend to be empirical in nature. This study combines both inductive and deductive approaches. The first step in the deductive process involves reviewing and evaluating existing literature in areas including theoretical models for creativity and usability to identify and formulate supporting theories for assessments pertaining to creative production, as shown in Section 2. The inductive process then involves reflecting on the three years of academic practice and observations for a creative production module delivered at undergraduate level, held by the teaching team that served as the basis for the case study presented later in this article. This reflective process has allowed the team to devise initial perspectives on their own experiences on student assessment, particularly with respect to the nature and range of work typically produced by students and how these ought to be taken into account for the new assessment framework. From the combination of the deductive and inductive processes described above, the new proposed assessment framework can be finalised and tested.

3.2. Evidence-based research

The evaluation and analysis of the proposed assessment framework is conducted via an evidence-based research approach. This is widely used in the field of health sciences, techniques of which can be adapted and applied in similar ways to computer science and engineering disciplines [61]. Doing so enables existing research statements and evidence to be synthesized towards drawing valid and new conclusions. Promoting evidence-based solutions are also desirable as they help to increase self-efficacy and enhance classroom practices [62]. For this article, an evidence-based approach has been applied during the evaluation stage through the use of actual student data spanning three years of course delivery. This data encapsulates student results in the form of their final grades in a quantitative format (represented on a spectrum of marks between 0 and 100), and a variety of creative outputs in the form of media artefacts (i.e. mobile apps for interactive digital games) that students have produced for their course assessment. This data is used as the basis for testing the validity and suitability of the proposed assessment framework.

3.3. Case study

In addition to the above, case studies also provide the benefit of being a well-established method by helping to inform of practical phenomena by focusing on aspects that worked well within a given setting, elements that have been achieved, and highlighting in detail issues of concern or dilemma in the given scenario. For this article, the examination of an individual case study offers a unique insight and body of evidence on the feasibility and effectiveness or otherwise of the system in question. However, it should be borne in mind that outcomes from individual case studies are typically not statistically generalisable [63] but can nevertheless be analytically generalisable [64]. For this article, given that the adopted case represents an exhaustive study of a single academic unit, the case study method serves as an invaluable source for gaining a deeper understanding of behaviours and observable patterns of the concerned unit. This also allows the results to be based on an explicit case of actual practice beyond that of a purely theoretical venture. Although most case studies tend to be qualitative in nature, this article will rely on the use quantitative analysis, especially for elements of assessment results and student feedback so as to provide additional objectivity. The case study is therefore represented in the form of a university undergraduate module in the UK that teaches students the fundamentals of creative media production (more information on this is given below). The case study also spans data covering three years of course delivery, encompassing a significant number of students, as will be detailed further below.

Hence, the combined use of deductive, inductive, and evidence-based approaches serves as the foundation in the evaluation of the feasibility and viability of the proposed assessment framework. In so doing, a range of demonstrative and testing processes are presented below, along with findings from this specific case study. Ethical approval has granted from the participating institution and informed consent has been obtained for all involved students prior to the commencement of data collection.

3.4. Research setting

The case study was conducted under the following setting:

a. The case involves a data collection period of three full academic years from 2019 to 2021 inclusive, capturing the assessment performance and learning experiences of approximately 150 students per year, which gives a total of approximately 450 students involved in this study.
b. The case is conducted in a British university, where the module is delivered to final-year undergraduate students as an elective module offered to a range of BSc (Hons) Computer Science programmes including Data Science, Artificial Intelligence, Software Engineering, Information Technology, and Cyber Security and Networks.
c. The typical characteristics of the students include the fact they have all studied fundamental topics in computer science such as programming, computer hardware, mathematical principles, algorithms and data structures, and operating systems and networks. Students on the course are typically aged between 18 and 21 years, and come

from diverse backgrounds in terms of geography, culture, and pre-university education. These characteristics may be considered relatively commonplace and hence not dissimilar to many other comparable institutions.

Students are provided a brief to produce a mobile game for an audience within a set age group. Students are given four weeks to complete the coursework individually. Each of three student cohorts for the three academic years under study are given a unique brief that presented the same problem, but under different scenarios such that a meaningful degree of uniqueness can be ensured for each cohort. The three scenarios mimic real-life game themes from the industry: car racing game in portrait screen, adventure theme in landscape screen, and bird-shooting in landscape screen, as shown in Fig. 3. The task specifications given to all students should cater for a range of requirements:

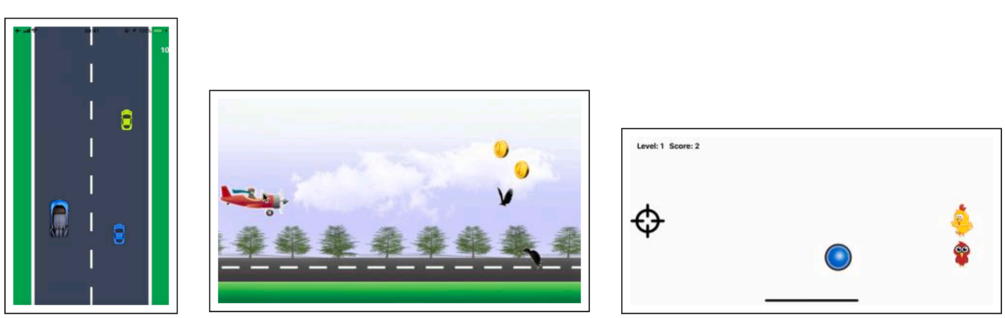
a. The nature and style of the final artefact must be sufficiently unique such that it would be extremely unlikely for students to source similar code or solutions from the Internet (for example, there may exist numerous hands-on tutorials and source code online for common applications such as calculators and popular games, from where which students may easily adapt or directly obtain content).
b. Students are expected to achieve the learning outcomes of gaining skills and attributes of writing an app using a well-supported mobile platform and development environment as well as handing issues of user experience and usability in the app design.
c. The set task is designed to enable students to complete the core requirements using the prescribed teaching materials, whilst also allowing a margin for motivated students to go beyond the core requirements in creative ways.
d. Guidelines on executing tasks of core requirements are provided for students, whilst students can engage with additional self-learning and research to explore and implement features for optional requirements.

Beyond these and as has been discussed to some extent in Section 2, the creative aspect of what students produce also represents a key outcome of the task [65] defines creativity as generating new ideas by developing current ones with individuality. This is also confirmed by [66] who claims that creativity is one's ability to use imagination to develop new ideas or forming variations of existing ideas. Following this principle, students are given opportunities in the task to develop a creative product based on a set of core criteria and guidance material. To achieve this, a general use case (i.e. details of how the product intends to be used by a set target audience) and an example showcase of a representative product (as developed by the teaching team) are provided to students as an illustrative example of what can be achieved. Students can employ the use of similar and extended methods of implementation depending on their design decisions to devise their own interpretation of the standard showcase. It can be anticipated that one of the biggest challenges for computer science and engineering students in engaging with creative production is their ability (or otherwise) in generating aesthetic assets such as images and sound: an element of production that is usually the remit for students in art and design as opposed to those in technical disciplines. Hence, in order to allow computing and engineering students to complete the task, the need for and use of aesthetic materials can be resolved via two approaches. The first is to provide students with a standard set of resource assets (mostly consisting of image files) that they can use for the task. This method has the advantage of removing the need for students to spend significant amounts of time creating unique and original images. The second is to encourage students to research and identify assets of their own accord using free-to-use and royalty-free libraries that are widely available in the development community. In doing so, students will gain a deeper appreciation of the importance and contribution of carefully chosen imagery and visual assets to their overall design intentions and practical implementation. Any included materials may then be cited and acknowledged using normal academic conventions.

3.5. Data measurement and collection

Final data collection comprised of the following format and processes:

a. Quantitative grades: Applying the above setting, all students spanning the three academic years take part in the designated assessment. The proposed assessment framework is then applied in the final marking of their submitted artefacts. This then leads to the creation of an overall final grade for each student which, as outlined above, is represented in the form of a score between 0 and 100, derived by awarding a mark for each component in the proposed assessment framework as will be detailed in the next section. This final grade serves as the overall judgement of a student's performance on the module.
b. The creative artefact: Students submit their completed work in the form of an individual project file that contains all the necessary materials for their mobile app. This typically includes source code, supporting visual and sound assets, and any other supplementary APIs or required materials for their artefact to be run on a marker's computer. Creative aspects of the artefact are judged according to the visual variation and originality beyond the standard solution (i.e. core requirements) that was provided to students from the outset.
c. Questionnaire at the end of the module: All students are asked to complete a short, standardised survey asking for basic feedback on their perceptions of the module content and assessment. The survey contains a total of five questions, which measures students' opinions using a 5- point Likert scale, as will be detailed during the analysis below.



(a) Car Racing (2019) (b) Air Adventure (2020) (c) Bird Shooter (2021)

Fig. 3. Common game scenes with random appearance of obstacles.

3.6. Data analytical approach

The collected data will be analysed using descriptive statistics to confirm basic features of the data, namely for student performance (quantitative grades), the grading of the creative artefact, and outcomes from the end- of-module survey. Descriptive tables for the experimental results will be produced in order to achieve decreased reliance on statistical significance as well as the ease of explaining findings to non-specialists [67]. Therefore, the decision was made to present metrics such as the mean, standard deviation, and counts.

In addition, further forms of statistical analyses have not been conducted for the following reasons. This study focuses on a macroscopic perspective of feasible assessment strategy, with a high degree of granularity. As such, the purpose is to test the validity of the framework as a whole. More advanced statistical techniques are usually employed in learner-centred research ([8] being an outstanding example for research of this nature), which is not the focus of this paper. The proposed framework is tested using a specific research setting as defined above. This framework can be generalised to other similar assessment scenarios within the discipline, which may employ different marking criteria. Other types of research with an agenda of pedagogy study and/or investigating the associations and impact of different assessment components have taken good use of advanced statistical techniques such as [17,26,32], which again is not the focus of this article, and therefore there is relatively little value to explore individual relationships among technical components that are covered by the learning outcomes. Descriptive analysis will suffice to offer general perspectives on the subject as a whole in terms of testing the feasibility of the proposed framework.

4. Assessment framework

The findings in Section 2 provide theoretical support for the assessment strategy of computing production process with creative requirements. As such, the final assessment framework incorporates three factors for the production: Function, Management, and Usability, as well as two attributes for creativity: core requirements and optional requirements. The proposed assessment framework for creative production for computing and engineering disciplines is summarised in Fig. 4. The framework illustrates thematic grouping of the assessment components, which informs the allocation of the marking criteria as detailed in Table 2. The remainder of this article will further justify the establishment of the framework and focus on deriving techniques that can be used to quantify a formal assessment of the involved factors and attributes within academic practice.

4.1. Factors for production

4.1.1. Function

In science and engineering programmes that involve creative production, learners usually possess strong technical background and skills in the software development field. Studies by [68,69] show that core learning objectives for these programmes typically revolve around coding and software engineering. Despite the multidisciplinary elements in creative computing subjects, it is essentially a software engineering process [2] where knowledge and skills in traditional topics such as requirements engineering, system design, coding, and testing are essential for the development of software artefacts. Functional elements are key indicators of the extent to which necessary technical developments are taken to deliver required features. In other words, all creative ideas that have been established during the design and requirements stage can be translated into a semblance of reality during the functional stage that emphasizes technical implementation. Using the case study set out above as the example, the required functionalities pertaining to the game's design, such as behaviours of characters, effects of certain environments, different levels, and player reward systems should be implemented accurately. Reliability is also included under this function indicator, for example, the product should be able to run repeatedly without crashing or error.

As shown in Table 2, the Function component required minor adjustments for each of the three years represented in this case study to reflect the slight differences in the scenarios given to each of the student cohorts. For example, in the Car Racing scenario, the Function category contains 'Roadmap Motion Effect' and 'Random Rival Cars', which would not make contextual sense in Air Adventure or Bird Shooter scenarios. Thus, these were alternatively designated as 'Background Motion Effect' and 'Random Obstacles', and 'Shooter Movement' and 'Random Birds' respectively. These minor adjustments are easily implemented and necessary for ensuring accuracy to the given task, and do not fundamentally alter the structure or use of the assessment framework. For the two components that are described below, such alterations were not necessary as they are not affected by the varying scenarios given to each cohort. Furthermore, feedback from the end-of-module survey and observations across the three years of course delivery also did not show evidence of any necessary change.

4.1.2. Usability

As discussed in Section 2.3, the ISO usability model serves as a useful foundation for presenting creative products. Each of its three factors and three attributes can be customised and adapted for the assessment framework. In terms of usability, this reflects the extent to which a

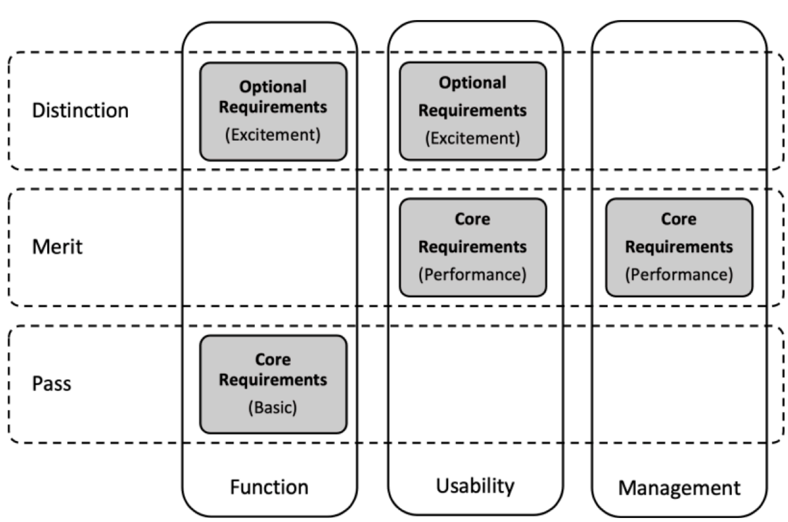


Fig. 4. Assessment framework for creative production.

Table 2
Quantitative assessment with variation of themes.

Production	Weight	Car Racing (2019)	DI	Air Adventure (2020)	DI	Bird Shooter (2021)	DI*	Creativity
Function	5%	Roadmap Motion Effect	2	Background Motion Effect	2	Shooter Movement	4	Core Requirements (Basic)
	5%	Constrained Car Dragging	2	Constrained Plane Dragging	2	Shooting Balls	2	
	5%	Random Rival Cars	2	Random Obstacles	2	Random Birds	2	
	5%	Collision Effect	5	Positive Collisions	5	Ball Movement and Collisions	2	
	5%	Game-Over Enabled	1	Negative Collisions	2	Collision between Balls/Birds	6	
	5%	Finish View	2	Game-Over and Finish View	3	Game-Over and Finish View	3	
	5%	Replay Enabled	1	Replay Enabled	1	Replay Enabled	1	
	5%	Score Keeping	4	Score Keeping	4	Score Keeping	4	
	5%	Smooth Running of App	1	Smoothing Running of App	1	Smoothing Running of App	1	Optional Requirements
	15%	Stretch Features	n/a	Stretch Features	n/a	Stretch Features	n/a	
Usability	5%	Easiness of Operation	3	Easiness of Operation	3	Easiness of Operation	3	Core
	5%	Screen Compatibility	1	Screen Compatibility	1	Screen Compatibility	1	Requirements (Performance)
	5%	Visual Impact	3	Visual Impact	3	Visual Impact	3	Optional Requirements
	5%	Engaging Factors	3	Engaging Factors	3	Engaging Factors	3	
Management	5%	Agile Management	1	Agile Management	1	Agile Management	1	Core Requirements (Performance)
	5%	Version Control	1	Version Control	1	Version Control	1	
	10%	Self-Reflection	2	Self-Reflection	2	Self-Reflection	2	
Total	100%		35		37		40	

* DI denotes the Difficulty Index, indicating the difficulty and challenge level of the assessment component, i.e. the technical implementation of certain features or the execution of particular tasks.

product delivers a user-friendly interface, visual impact, and engaging features. While these appear to be largely subjective factors, the approach proposed below will attempt to objectify these elements to allow for more reliable assessments of student work.

4.1.3. Management

Knowledge and application of management principles are essential assessment components of learning for students who have engaged in what is a typically an extended production process of at least several weeks or months. More specifically, a combined use of version control and Agile management methodologies should be applied appropriately during creative production as they closely reflect industry practices, and to which students should become acclimatized. In further support of this, work by [51] showed that the design quality of project goals and tasks within an Agile management process can significantly impact project success, and hence students' ability in devising and allocating tasks throughout their project should therefore be considered a valuable learning outcome. Practically, management aspects during the assessment of creative production can be appraised by the sum of four attributes: the definition of tasks, the frequency of updates to a Kanban board, the number of commits to a version control repository, and the extent of documentation of commits. These four elements can also be consistently measured and applied in both individual and team-based projects.

Individual development can also follow an Agile process without being involved in a team. The Agile methodology is based on principles such as iterative and incremental development, continuous improvement, and flexibility, which can be applied to individual work as well. One of the key aspects of Agile methodology is the focus on delivering value in small, incremental iterations. As an individual, the developer can break down the work into smaller, manageable tasks and prioritise them based on the given values. This can help the developer stay focused, motivated, and make progress towards the goals. Another important principle of Agile methodology is continuous improvement. Individual developer can apply this principle by regularly reviewing the work and reflecting on what worked well and what could be improved. This can help to identify areas of improvement so that approaches can be adjusted accordingly. In summary, while Agile methodology was initially designed for teams, its principles can be applied to individual development as well. By breaking down the work into smaller tasks and focusing on delivering value in small, incremental iterations, and by continuously reviewing and improving the ongoing work, individuals can adopt an Agile approach to development process.

4.2. Attributes for creativity

As mentioned in Section 2.2, a creativity requirements model can be adopted in the assessment regime to encourage creativity from students. The assessment strategy is designed to alleviate the barrier of aesthetics and to promote creativity for electronic engineering and computer science students, which will combine core-requirements with optional-requirements to promote creativity and innovation in the technical disciplines. By combining compulsory and optional requirements in assessments, it is feasible to evaluate students' comprehension of the core course material while also providing opportunities for personalisation and exploration. This approach ensures that students are challenged to achieve the learning outcomes of the course while also allowing them to engage with the material in a creative way that is meaningful to them. Fig. 4 and Table 2 show the mapping of the core-requirements and the optional-requirements in the assessment factors (details of Table 2 will be further elaborated later in Section 4.3). The mark allocation for the Function, Usability, and Management factors is arranged to reflect different academic grade bands: core-requirements with the basic-requirements only leads to the Pass band, the entire core-requirements contributes to a Merit, and all the optional requirements grants a Distinction.

The basic-requirements originate from the Function factor. As computing and engineering disciplines, the technical implementation of the software artefact demands fundamental concepts and skills that are essential to the course, and therefore the majority of the assessment elements in the Function category are the minimum conditions to pass the course, which refer to the basic learning outcomes of the studied modules.

The performance-requirements include a range of expectations for the given academic discipline. This involves some of the Usability assessment elements, for example, the easiness of operation and screen compatibility which are counted as core disciplinary skills. The Management factor for the production process, although being regarded as soft skills for computing and engineering students, demands effective planning and competent execution within a given timeline [70]. This comes under the core-requirements umbrella where students need to be able to develop strategies to overcome the challenges that come with production management.

Optional-requirements are not mandatory for students to cater in the given discipline, which gives students the freedom to customise the existing features or add new features to deliver outstanding user experience. With regards to Functions, a portion of marks (e.g. 15% in the case study) can be reserved for students to evidence and perform any 'stretch' tasks, such as going over and beyond core requirements not set out in the original assignment but nevertheless demonstrates initiative and features that further enhance their project, which may include aspects of additional functionality, experience, and feature sets. These additional features are regarded to cater for the excitement-requirements in the creativity model [33], which equates to the optional-requirements. Another factor that contributes to the excitement-requirements is Usability where visual impact and engaging factors play a major role in user experience. Matters concerning aesthetics will also make an impact on the final product: for example, the nature, extent of, or combination of colour usage, the choice of images, font styles, the use of sound effects or music, will all inevitably influence an assessor's perception of the product. However, assessors must detach personal perceptions from the judgement of students' work so as to avoid subjective opinions [71]. Therefore, aesthetics should not be taken into account during the assessment of a creative product for computing and engineering students, unless relevant topics have been provided in the curriculum for the specific requirements of the set assignment.

4.3. *Quantitative assessment for large classes*

Quantitative assessment refers to the use of numerical or statistical measures to evaluate a student's performance or learning outcomes. It is often more efficient and suitable for marking large classes for the following reasons. First is objectivity: Quantitative assessment is less subjective than qualitative assessment, as it relies on numerical data rather than personal judgments [72]. This means that the grading process is more standardized, reducing the potential for bias and ensuring consistency across a large number of students. Second is time-saving: Quantitative assessment methods are typically faster to grade than qualitative assessment. This means that instructors can assess a larger number of students in less time [73]. Third is scalability: Quantitative assessment methods are easily scalable, which means that they can be used to assess large numbers of students without requiring additional resources or time. This is especially important for courses with large enrolments, where grading can become a time-consuming task. Fourth is the plethora of analytical techniques: Quantitative assessment data can be easily analysed using well-established statistical methods [74], which can provide insights into overall student performance, identify areas of strength and weakness, and inform instructional decisions. Overall, quantitative assessment can improve the efficiency of large class assessment, although appropriate methods need to be in place to ensure all learning outcomes are evaluated.

Using the assessment framework as shown in Fig. 4, the implementation of the final product can be fully quantified to reflect a student's effort and level of achievement. Table 2 depicts examples of the full grading criteria for the production of the three respective cases presented in Fig. 3, which will be elaborated in later sections. The assessment feedback complies with the proposed framework whereby the marking elements for each case are categorised into three groups to reflect the production process: function, usability, and management. The usability and management categories are largely similar across the three years as there are common standards and expectations for associated practice in these areas. The function category may be customised based on the case itself, namely given any variations in an application design or theme (for instance, a driving game may be very different to an adventure or educational game). Each element within the full grading criteria should follow the example in Table 3 to quantify a student's effort and achievement. DI (difficulty index) refers to the level of technical difficulty to implement the expected component. Depending on the purpose of the intended application, the quantified assessment criteria can also be adjusted to reflect the specified goals of use as determined by the teaching team. The difficulty levels for Usability and Management are consistent across the three years given the similar nature of the coursework. Function refers to programming, for which the DI was

Table 3
Linear marking of the implementation of random obstacles.

Component	Marks
Base mark for the attempt of deploying obstacles	1%
Randomness in obstacle's location	1%
Randomness in obstacle's speed	1%
Randomness in obstacle's quantity	1%
Randomness in obstacle's appearance	1%
Total	5%

moderately incremented each year for two reasons. First, the development environment (Xcode in this case) evolves frequently every few months, offering new libraries and features which make for easier and quicker development times. Second, the DI increment also helps to reduce the possibility of plagiarism across cohorts.

The quantitative assessment approach can be implemented using a simply 'box-ticking' practice, which essentially functions as marking rubrics – research has shown that a carefully designed marking rubrics can greatly reduce the marking time and improve the assessment efficiency whilst maintaining the assessment effectiveness [75,76].

One of the recognised and common criticisms with respect to feedback given to students is that of subjective comments given by markers and where learning outcomes could (and perhaps should) have been assessed in a more objective fashion [77]. This issue may manifest in the form of feedback appearing the form of subjective or biased expressions such as "I like your app", "I find your app very attractive", "I lost interest in your app a few seconds after playing it", and so on. Providing feedback comments can lead to differences in opinions between educators and students, which may also lead to positive or negative biases towards individual students [78]. Feedback given to students therefore requires judgements that are trustworthy and perceived as fair by students. The marking of students' work should blend transparency and consistency based on the facts of what a student has produced, i.e. to ultimately reflect the quantity of effort a students has put in and the actual results that have been achieved. The following discussions will demonstrate an example of quantifying the student efforts in implementing creative elements.

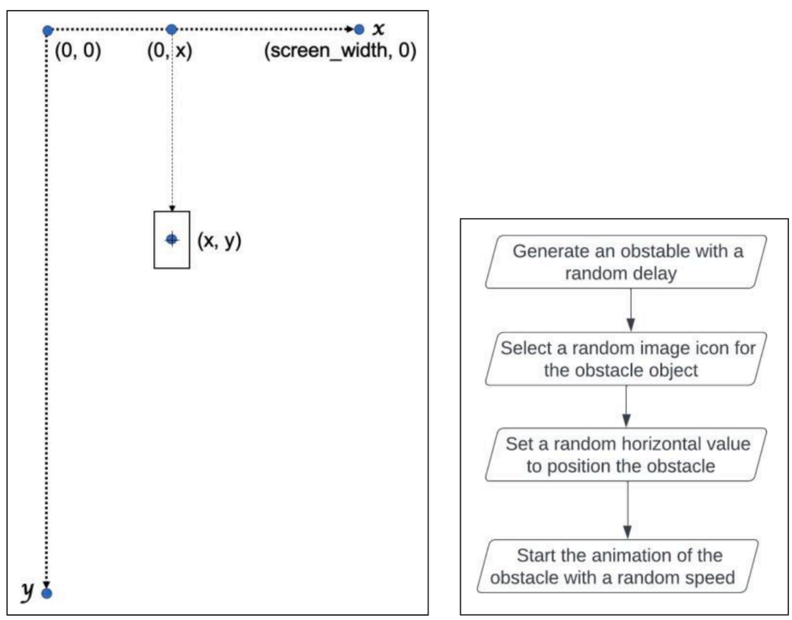
5. Quantifying creativity and efforts

User experience can be measured using an objective and/or subjective approach, as explained in Section 2.3. However, measurement approaches can often be time-consuming and resource-intensive, which can be difficult and unrealistic to achieve during normal course delivery. As educators, an element of utmost importance in academic assessment is to motivate students by rewarding effort and fostering achievements [79]. Consequently, any assessment mechanism within a curriculum must be designed to deliver a positive impact on student performance. With this mind, the assessment of creative elements in an assignment can place emphasis on a student's endeavour in implementing factors that contribute to the overall user experience. To achieve this, the case presented here outlines an example of evaluating effort in implementing creative features. Fig. 3 shows potentially common game scenarios where there exist a main avatar (such as a player-controllable character or vehicle object) and a series of continuous and collidable obstacles that may need to be avoided or captured. These scenarios also represent realistic and suitable teaching examples, mirroring typical set-ups that can be found in common commercial games such as car racing titles, adventure games, and those in action genres [80]. The three scenarios in Fig. 3 are each applied as the respective case studies for the three years documented in this research. The common feature represented in each of the three scenes is that of the random appearance of collision obstacles that must be avoided or captured by the player character, i.e. the rival cars in the racing game, the black birds and the golden coins in the adventure scene, and the birds in the bird-shooting scene. The following example illustrates how students' abilities and efforts were assessed for the implementation of the randomness of these collision obstacles during the production process.

For the scenarios presented, developers should strike a balance between the ease with which the game may be played and the challenge it offers to players by varying the intensity of the obstacles. The game's design must contain certain challenging elements to increase its appeal [81,82]. For instance, if there are no obstacles in the game scene over a perceivable period of time, users may lose interest and exit the game. On the other hand, too many or difficult obstacles would also impact the overall user experience in games [83] – i.e. if there are too many obstacles over a short or frequent periods, the game is likely to be perceived as being too difficult to play. In essence, the creation of obstacles is a determinable but subjective process that is implemented within program code, but the end result should ultimately enhance the game's appeal to users by applying an appropriate balance of intensity. To achieve this, the generation of obstacles can be achieved by employing a stochastic process in four areas: some degree of randomness in the location of an obstacle's emergence, a degree of random speed for each obstacle, a random quantity of objects, and a random appearance (such as colour, car model). All these may be applied in any given time of the game play. As shown in Fig. 5(a), the random location of emergence refers to the position of an obstacle when it first appears from the top of the screen (Fig. 5(a) demonstrates the example of a scene for a simple car racing game in Fig. 3(a)). Considering the screen as a coordinate system, the horizontal value of the obstacle position is a random number between 0 and the full width of the screen.

Taking the car racing game again as the example, obstacle cars should move vertically from the top to the bottom of the screen, after which it should disappear, giving the players the illusion that the main player's car is overtaking obstacle cars. Fig. 5(b) outlines the basic logic and flow of the procedure for a random creation of obstacles in terms of their location.

(1) First, the system starts creating an obstacle after a random delay. The shorter the delay, the more obstacles will appear on the screen, and hence this is a key factor for determining the quantity of obstacles on screen at any given time.



(a) Position on Screen (b) Flowchart

```swift
//Randomly create an assortment of obstacles to appear on screen
func obstacleDynamics() {

    //Random delay to start the obstacle generation
    for index in 0...9 {
        let delay = Double(self.obstacleDelayArray[index])
        let when = DispatchTime.now() + delay

        //Create one obstacle after delay
        DispatchQueue.main.asyncAfter(deadline: when) {
            let obstacleView = UIImageView(image: nil)
            var imageArray: [UIImage]!

            //Randomly select an image icon for the obstacle
            imageArray = [UIImage(named: "car1.png")!, UIImage(named: "car2.png")!, UIImage(named: "car3.png")!, UIImage(named: "car4.png")!,
                UIImage(named: "car5.png")!, UIImage(named: "car6.png")!, UIImage(named: "car7.png")!, UIImage(named: "car8.png")!,
                UIImage(named: "car9.png")!, UIImage(named: "car10.png")!]
            obstacleView.image = UIImage.animatedImage(with: imageArray, duration: 0.4)

            //Randomly select a horizontal position for the obstacle to appear
            obstacleView.frame = CGRect(x: self.W*0.25+CGFloat(arc4random_uniform(UInt32(self.W*0.5))), y: self.H, width: 80, height: 80)
            self.view.addSubview(obstacleView)
            self.view.bringSubview(toFront: obstacleView)
            self.obstacleViewArray.append(obstacleView)

            //Randomly assign a speed for the obstacle movement
            self.obstacleDynamicItemBehavior.addItem(obstacleView)
            self.obstacleDynamicItemBehavior.addLinearVelocity(CGPoint(x: arc4random_uniform(UInt32(200))*(-1), y: 0), for: obstacleView)
            self.obstacleCollisionBehavior.addItem(obstacleView)
            self.obstacleDynamicItemBehavior.elasticity += 0.1
        }
    }
```

(c) Code Snippet (Written in Swift)

Fig. 5. Technical implementation of generating random obstacles.

(2) Second, a random image icon will be assigned for the created obstacle object. This will ensure the obstacles will look different from each other and determines the actual visual appearance of the obstacles – take a car avatar for instance, the appearance of the cars may vary in colour, size, model, shape, etc.
(3) Third, a random horizontal position on the top screen border will be set as the starting position for the obstacle to appear, which is represented as a random integer between a range of 0 and screen width. This will lead to the obstacles popping out from various locations.
(4) Fourth, when launching the animation of the obstacle, it moves from the top of the screen to the bottom screen in a randomly varied speed. The speed of the animation dynamics can deliver the effect of a car moving in a faster or slower speed, which also contributes to the stimulating factor of the game.

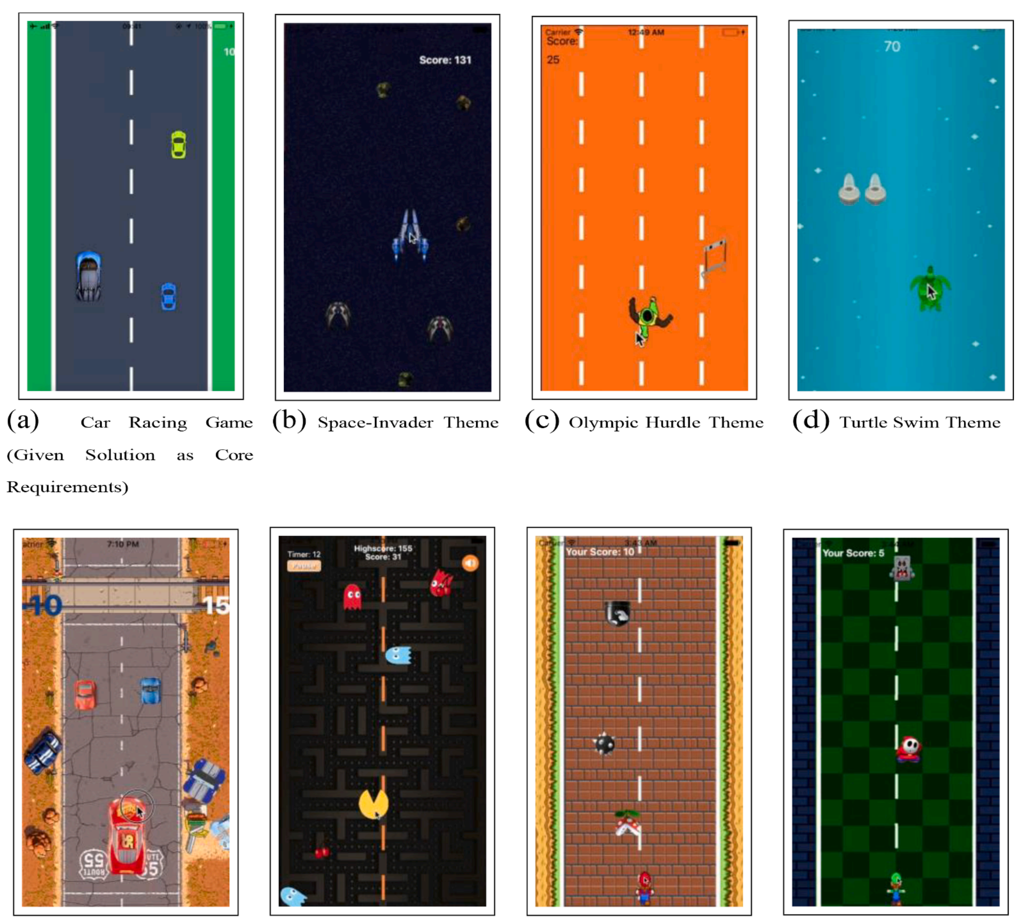
Although the flowchart only contains four steps, actual program code may of course be more expansive depending on the development environment and necessary syntax – Fig. 5(c) shows an example of source code written in Swift programming language. The style and the order of code may also vary depending on students' personal design and implementation choices. From these, the associated marking rubrics could then potentially follow a linear pattern as shown in the example in Table 3, although this may be adjusted depending on specific learning outcomes in actual modules.

6. Assessment outcomes

The assessments documented in the three case studies were designed with the intention of providing students with the opportunity to express their learning in the module and application of their acquired skills in a creative and non-prescriptive manner. The designed assessment framework consists of mandatory requirements for functionalities, usability, and management, whilst leaving sufficient margin for students to generate variations in terms of visual design.

6.1. Student performance

- *A large variety of creative themes in the software artefact:* This is indeed a tangible outcome of this research. Students have been given abundance of options to be creative as long as the core requirements are met – the practice of combining core requirements with optional requirements has been proven to quite effective to promote creativity and innovation in the design and engineering disciplines [33,84]. Positively, this intention has been realised as evidenced in many of the work that have been submitted, leading to genuinely unexpected (yet suitable and effective) outcomes. Students are able to derive highly nuanced and individual variations on a theme: for example, the car racing case leads to virtually each student producing their own interpretation of what might be considered as 'racing', and even those using the standard image assets are able to devise solutions that are significantly different to the standard solution that has been previously given. Fig. 6 shows a selection of the students' production based on the given scenario in 6(a), which showcases the variations of creative themes based on a fixed set of core requirements. In the final account, and somewhat unexpectedly, each student project is indeed reflecting the individual idea of the appearance design, despite the prescription of a standardised brief, reflecting the



(a) Car Racing Game (Given Solution as Core Requirements) (b) Space-Invader Theme (c) Olympic Hurdle Theme (d) Turtle Swim Theme

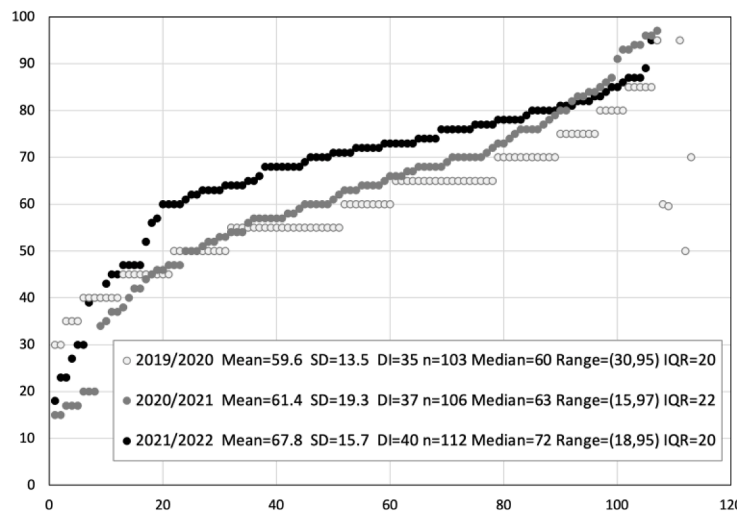
(e) Lightning McQueen (f) Pacman Theme (g) Super Mario Theme 1 (h) Super Mario Theme 2

Fig. 6. Variations of students' creative production based on the core requirements as shown in the given solution (a).

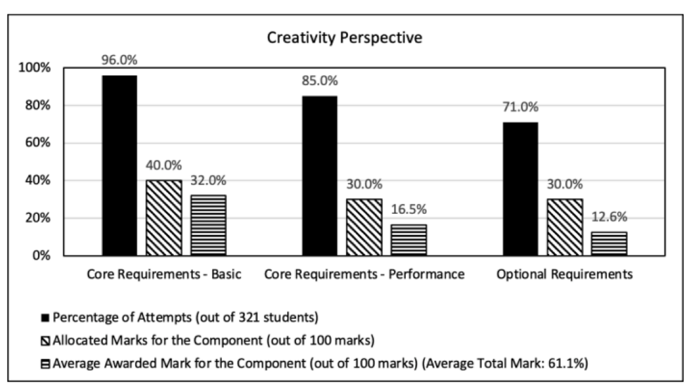
individuality of students and their design decisions. The allowance for creativity has greatly motivated students in the learning process, as previously stated by research in [85].

It is worth noting the work in Fig. 6(e) to 6(h) featuring well- known game genres, for example, Lightning McQueen [86], PacMan [87], and Super Mario [88]. Despite potential controversial issues about copyright, this practice can be justified for two major reasons. First, the produced work are strictly used for study and research and will not be used for any commercial purposes. Second, the conducted study complies with the fair use policy of the World Intellectual Property Organization (WIPO), which states: "*The fair use of a copyright work, for purposes such as criticism, comment, news reporting, teaching, scholarship, or research, is not an infringement of copyright* " [89]. As an outcome of this practice, the familiar concepts and images of these renowned game genres have enhanced students' learning motivation and stimulated their creativities, as previously revealed by [90].

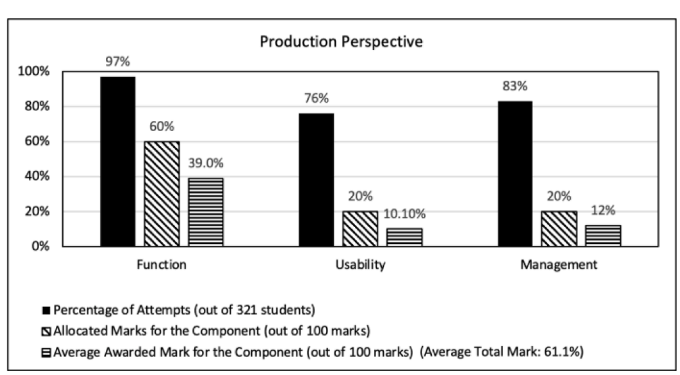
- *Healthy Grades Distribution:* In terms of academic performance, students have generally achieved notably high levels of performance for each of the case studies, as shown in Fig. 7(a) where each dot represents an individual student. There are healthy mark distributions of assessment results from the study of all the three years. Despite the slight increase of difficulty level for the given assessment, students'



(a) Mark Distribution from Three Years



(b) Student Engagement from Creativity Perspective



(c) Student Engagement from Production Perspective

. 7. Student grades and engagement.

performance is improving with a steady pace with an average mark rising from 59.6 to 67.8 after two years. The marking criteria from Table 2 can be essentially viewed from two perspectives: all the quantitative marking elements on table the can be categorised either from creativity perspective (i.e. core requirements and optional requirements), or from the production perspective (i.e. function, usability, and management).

- *High Student Engagement:* Fig. 7(b) and (c) show the allocated marks for each component from these two perspectives, as well as the students' average mark for each component, which is based on the collective results from all the three years' study involving a total of 321 students. The black bars in the figures present the percentages of student attempts on the respective assessment categories. As can be seen from the creativity perspective, nearly all students have attempted all the compulsory components that require technical skills from the computing and engineering discipline. The proportion of students attempting the optional components decreases as additional technical challenges would incur, although the percentage still represents the majority of the student cohorts. As for production perspective, nearly all students have attempted the Function category which is highly technical. This is as expected for science and engineering students. Some students may underestimate the importance of usability and production management, leading to a decline in attempts for these two assessment categories, although the total percentages of attempts still represent the majority of students. These two figures overall have shown positive relationship between the assessment and student engagement.

6.2. Student feedback

On the completion of the final assessments, standard student surveys have been conducted and their reported experience is summarized in Table 4. The average (AVG) and standard deviation (SD) are based on the Likert scale from 1 to 5. The analysis presented in Table 5 further summarises keywords as written by students in the survey. This is constructed by counting the frequency of the use of specific words to show the number of times a particular attitude or opinion was raised. In summary, the proposed assessment framework has promoted the following reported benefits in learning amongst students.

- *Intellectual stimulation:* The proposed framework has engaged students by encouraging and rewarded their effort in achieving quantifiable results. This therefore extends beyond merely achieving technical outputs and required students to engage with design and aesthetic challenges, the demands of creative forms of production, project management, as well as core technical skills. It was also reported in previous work that students possess intrinsic desires to learn, and will do so more effectively if they believe what they are being taught will matter in their lives [91]. This may be gleaned from certain keywords in Table 5 where the module provided 'industry experience' and 'practical' elements of study, which ultimately pertain to skills that students may require and use in their future careers.
- *Being challenged to produce their best:* Interestingly, students have felt strongly that the module challenged them to produce their best work. Students are expected to familiarise and become proficient with the programming language that was determined by the nature of artefact. This therefore required dedication and self-learning in order to achieve the required assignment outcomes. In doing so, students are able attain higher levels of achievement by exercising their skills and knowledge by experimenting and incorporating suitable and additional features within their solutions (as discussed above) to distinguish themselves from others, and thus represented a main avenue through which they are challenged to go beyond the basic requirements set by the assignment.
- *Ability to explore concepts in depth:* Students are encouraged to expand on their knowledge and skillsets beyond the core content prescribed by the teaching materials, even though these are sufficient in allowing them to achieve the basic requirements laid out in the assignment. In this way, students are motivated to branch from key concepts to develop their own interests and expertise, which could eventually be applied to their final product. Higher-achieving students are typically able to develop their knowledge and skills in ways that are directly relevant to project outputs as well as evidence sustained self-learning and problem solving.
- *Abiltity to apply knowledge to practice:* The pedagogic approach in the module has provided the basis for students to apply theoretical knowledge within dedicated practical sessions throughout the duration of the module. This structured format has promoted the gradual acquisition of required skills that pertains to various elements of the assignment. Students can then reflect on how theoretical knowledge and examples could be applied to their final product.
- *Clear assessment criteria.* The grading criteria are explicitly defined at the outset for each element of the product (as laid out in the full grading criteria in Table 2), and thus the cumulative result of all elements reflects students' overall achievement. Beyond this, students are also regularly reminded of the softer requirements of assessment during the production stages of their work, including the need to engage with project management principles, the regular use of version control, and the need to document their design decisions and critique of the final product in their written report. This has helped regularly to steer students towards the main goals of the module and to ensure they produced relevant work.

Table 4
Student experience.

	2019 $n = 103$		2020 $n = 106$		2021 $n = 112$	
	MEAN AVG	SD	MEAN AVG	SD	MEAN AVG	SD
Intellectually stimulating	4.1	0.9	4.2	1.0	4.2	1.0
Challenged to achieve the best work	4.0	1.0	4.3	1.0	4.4	0.9
Opportunities to explore ideas in depth	4.0	0.9	4.6	0.8	4.6	1.0
Opportunities to apply knowledge	4.2	0.6	4.5	0.1	4.6	1.1
Well organised and has run smoothly	4.0	0.7	3.9	1.1	4.0	1.0
Assessment criteria is clear in advance	4.0	0.9	4.2	1.1	4.3	0.8

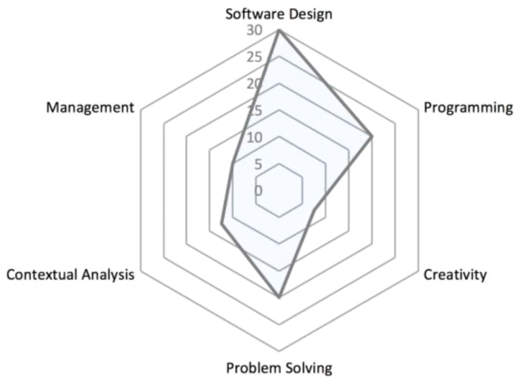
Table 5
Keywords in Students' Written Comments (54 Responses).

Rank	Keywords*	Frequency
1	"interesting" / "exciting" / "fun"	31
2	"learned" / "knowledge" / "gain"	29
3	"great" / "good" / "nice" / "cool"	27
4	"industry experience" / "practical"	26
5	"clear" / "easy"	18
6	"challenging" / "hard" / "stimulating"	12

* Keywords counted manually as the sum of all the included synonyms as shown. No exclusion criteria applied.

6.3. Observed benefits

The radar diagram in Fig. 8 summarises the knowledge and skills that have been gained and developed during the module's learning journey. The calculation of the skill gains in the radar diagram are based on weighted assessment strategy that is explained in Section 4. As may be expected, elements of software design, programming, and problem solving are those that are developed the most. These have received



. **8.** Hexagonal radar of assessed knowledge and skills.

noticeably higher focus compared to other skills as they serve as necessary requirements of the disciplinary assessment and are delivered as part of core content during teaching sessions. Attributes such as management, contextual analysis, and creativity have also been acquired through the integrated approach of the proposed assessment strategy. This result may point towards future opportunities for certain elements to be further reinforced depending on the nature of the subject, which could lead to additional layers of quality in terms of project outputs.

7. Conclusions and reflections

7.1. Conclusive findings

There has been a barrier for students in electronic engineering and computer science students to pick up creative production subjects, whose disciplines usually possess technical competencies in the programming side of production. Creative design and artistic skills may not be within their remit, areas of which are naturally catered for in art and design disciplines. This often leads to difficulties in applying established pedagogies, especially from the artistic and creative standpoint. The success of traditional well-established pedagogies for technical subjects often cannot be easily mapped to the field of creative production.

This article has demonstrated an assessment strategy through which creative production subjects can be firmly integrated within a wider study pathway, where students may gain various skills spanning both technical and non-technical areas that are critical for a more wholesome learning experience. A proposed assessment framework for developing creative applications within the computer science and engineering disciplines of UK Higher Education institutions has been outlined and evaluated in a real academic setting spanning three years of actual classroom experience, and in doing so a gap has been addressed in existing academic practices for cross-disciplinary courses. The review of existing theories leads to the prepositions for three key assessment factors for computing production including function, usability, and management, as well as two attributes for creativity: core requirements and optional requirements. The assessment framework is subjected to a combination of inductive and deductive approaches based on data and evidence collected in the form of case studies spanning a total of three years of course delivery in a real learning environment. The teaching and assessment presented in this case study are designed to alleviate the barrier of aesthetics and to promote creativity for electronic engineering and computer science students. The practice of combining core requirements with optional requirements has been proven to be quite effective to promote creativity and innovation in the technical disciplines. Collectively, the results demonstrate encouraging messages from a number of educational perspectives derived from students and assessment results, particularly given that creative production remains a relatively new discipline within the context of more established topics in the field of computer science. Overall the proposed assessment framework has proven to be effective and efficient in examining creative components that normally tend to be perceived subjectively. In the meantime, the assessment strategy has also fostered students' creative abilities in their productions.

7.2. Research strengths

The crux of the proposed framework emanates from its composition of the three core components of function, usability, and management that is reflects the nature of work that is commonly produced in courses such as that described in this article. It has been demonstrated that the value in this approach is that it offers a consistent and explicit set of criteria that may be adhered to by both students and assessors to ensure academic expectations are met yet, at the same time, offer degrees of flexibility so as not to restrict the type of work that can be produced. As documented above, despite the provision of a standardised assessment brief for each of the three years in the case study, students are consistently able to evidence significant variance in the type of work that they produced to satisfy the assessment criteria as well as impose their own creative ideas and interpretation into the final solution. As part of their experiences, students have reported that the framework has helped to promote greater intellectual stimulation, challenged students to produce their best work, enabled students explore concepts in greater depth, encouraged their ability to apply knowledge to practice, and provided a clear assessment criteria. Crucially, beyond these perceived advantages, the framework allows for a more systematic approach towards the inclusion of creative aspects of content in technical courses that may otherwise be neglected or, as has been discussed, assessed in ways that are usually highly subjective, if at all (leading to, in extreme cases, complaints from students regarding poorly considered assessments). The framework can thus be directly incorporated or adapted by educators that have similar requirements and characteristics in their course design and delivery to promote a more consistent balance between technical and creative content, as well as a more explicit learning and assessment structure.

In reflecting on the contributions and strengths of this study, these may be categorised into three core areas: Theoretical contribution, methodological approach, and practical, evidenced-based outcomes.

- *Theoretical contribution:* The article focuses on addressing a notable gap in the need for an assessment framework suited to the teaching of large undergraduate cohorts in multidisciplinary contexts. The research has proposed and evaluated a systematic and objective assessment framework that may be directly employed in such scenarios that can enhance the efficiency and acknowledgement of technical and creative aspects of student work. The proposed assessment framework also incorporates notable elements from existing theories and models in areas of student assessment, with particular elements drawn from the creativity requirements framework (as discussed in Section 2.2) and the ISO usability model (Section 2.3). These aspects therefore contribute to enhancing the theoretical basis and reliability of the proposed framework, allowing it to be further adapted as a tailored solution for assessing creative outputs in computing and engineering disciplines.
- *Methodological Merits:* The study's strengths in methodology pertain to combined use of inductive and deductive approaches, evidence-based analysis, and a case study spanning three years of data drawn from undergraduate course delivery. The mixed methods approach serveds as a robust approach, allowing for various perspectives to be considered in terms of theory, data sources, and eventual analyses. The use of varying methods also enables an important balance between theoretical considerations, practical experience, and data from actual student outcomes, which contributes to a more rigorous evaluation of the framework than what might otherwise be possible. The quantitative assessment approach, as

outlined in Section 4.3, is also a notable strength as it is designed to assess classes with large cohorts in an efficient yet reliable manner. One of the main strengths of the proposed assessment framework resides in its composition of transparent criteria that can each be objectively determined for student work. The quantitative elements of the framework also provide scalability and the option to perform further analytics for student results, which addresses existing difficulties due to subjective judgements of student work, as well as potentially ease resource constraints in large class scenarios.

- *Practical, evidenced-based outcomes:* The study demonstrates strengths in the use of practical, evidenced-based outcomes. One element of this is evidenced in the inclusion of industry techniques in the form of version control and Agile management methodologies as part of the assessment framework (see Section 4.1.3). These components thus allow the proposed framework to align with real-world scenarios as well as formalise their use among students, thus further preparing graduates with necessary skills for their future careers. These strengths are also reinforced by the evidenced-based evaluation, as derived from the results and feedback from students across three-years of academic study, as presented in Section 6, that demonstrate positive outcomes in the form of varied creative designs, intellectual stimulation, and clear assessment criteria. Consequently, beyond the core delivery of course material, the study has also shown how aspects of technical and creative work may be promoted whilst maintaining objectivity and efficiency in assessment. The practical applicability of the proposed assessment framework is therefore its underlying and most poignant strength. Educators in similar courses could potentially adopt and/or further adapt the framework to suit their own teaching contexts and curricula.

7.3. Limitations

Aside from the strengths noted above, there are some limitations that must be borne in mind. First, the applicability of the framework to other disciplines or subject areas may be limited given that the design of the framework is based on the unique characteristics and requirements of the case presented – i.e. that of a technical undergraduate course with creative elements. Therefore, the proposed framework may need to be adapted or extended to accommodate other types of student work, such as team-based projects or varying forms of creative outputs, such as web applications, game development, or other technical artefacts containing artistic forms of expression. The quality and ultimate deployment of the framework is also reliant on the composition and clarity of the designated rubric, which would require significant effort and expertise to develop, especially for complex or multifaceted assignments that go beyond the case presented in this article.

The data collection and analysis in this study is also primarily dependent on quantitative measures in the form of student results and feedback surveys. This may be enhanced through the inclusion of additional qualitative data sources, such as interviews or focus groups conducted with students and the teaching team, which would provide deeper insights into student experiences, perceptions of the assessment framework, and practical implementation.

7.4. Recommendations

A number of caveats should be borne in mind when the research outcome of this article is being applied to other settings. The first being that as a single case study on a UK context, the reported outcomes and experiences may likely differ according to individual institutions and the many variations in course design as well as regional and cultural differences. Be that as it may, the structure and approach documented here can certainly be used as a guideline for similar assessment content in comparable courses, particularly those involving multidisciplinary coverage, and as part of the normal process of sharing best practices amongst educational institutions. Second, as in other rapidly changing fields of study, creative productions such as that of mobile app development, will continue to grow and evolve depending on the emergence of new trends and technologies, and hence the results and the proposed framework will also undoubtedly change as a result of new practice. The challenge, therefore, is the persistent need to keep fully abreast of new trends such that course content can maintain its value and currency, while also stimulating and rewarding student learning and achievement. Third, future opportunities for developing certain taught and assessed elements can be refined and reinforced, such as the role of creativity and project management, which could lead to additional layers of quality in terms of project outputs. Finally, ongoing improvements to courses must take priority and are required perennially to maintain and enhance student experiences wherever possible to ensure students are equipped with necessary knowledge and skills for their future careers.

7.5. Future work

There are a number of key areas that would warrant future work to extend on the case presented here. First, there is potential for the assessment framework to be extended to incorporate a wider spectrum of scenarios and types of student work. This may be produced in the form of a more comprehensive set of assessment criteria that may be added or removed from the framework according to the demands of an assignment or course content, thus allowing for customised elements to be deployed by instructors as necessary. Additional criteria may also include broader descriptions for different forms of creative and artistic work, as well as technical competencies that may be evidenced across a varied curricula within computer science and engineering disciplines.

It would also be interesting to promote a balance between technical and creative content - further studies could expand on how this balance can be achieved and its impact on students' learning outcomes. For instance, it would be worth investigating whether there any specific trade-off in balancing the technical and creative aspects, and to address the challenges with mitigating approaches. This can be achieved by looking into individual assessment component and their associations among each other via an extensive data analysis using advanced statistical techniques.

Other, more challenging avenues for future development include the examination of the role of AI in the production of technical and creative content. Recent advances in the field have witnessed rapidly expanding AI-powered applications that are able to generate often remarkable visual imagery (pictures, videos, etc.) as well as technical solutions (such as ChatGPT providing programmatic solutions) through a series of simple requests given by a user. As in all academic disciplines, and not solely confined to this article, this leads to concerns of academic integrity and the production of authentic content from students, and how this may be accurately detected. As potentially effective as the proposed framework might be, it is not immune to the challenges of detecting genuine work produced by students themselves. Future work will therefore need to include developments in such areas, and somewhat urgently, especially to incorporate more advanced forms of content detection and validation, such that any grade that is awarded to the student does, indeed, reflect their ability and skillset.

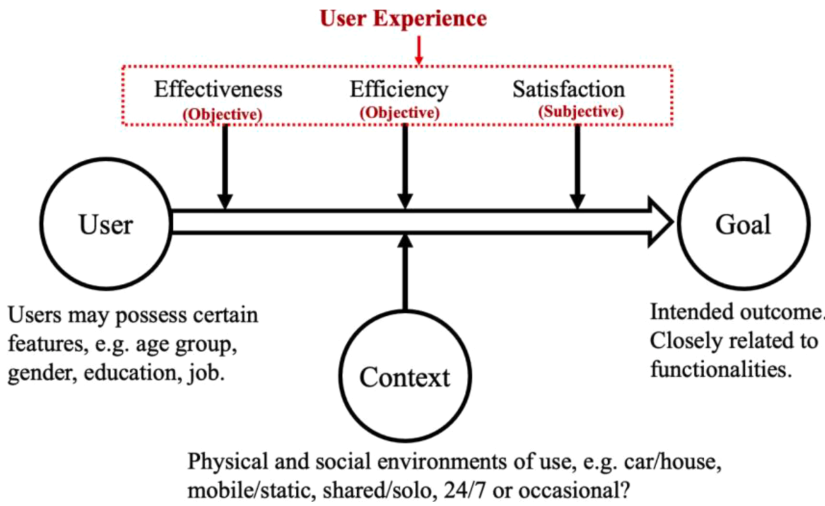
CRediT authorship contribution statement

Xianhui Che: Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Barry Ip:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Appendix A. Interpretation of the ISO Usability Model (Based on [44])



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