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Investigating varied pedagogical approaches for problem-based learning in a fire safety engineering course

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Abstract

Fire safety engineering is a critical component of a well-rounded engineering undergraduate curriculum but is understudied in the context of engineering education literature. Guided by previous work in problem-based learning, we conducted a multiple case study structured around three sections of a fire safety engineering course for students across engineering programmes. Our goal was to develop a better understanding of the impact of different pedagogical approaches on students. These approaches were chosen for study because they align with predominating approaches to industry practice in fire safety engineering. Classroom observations and student coursework from each of the three sections were used to evaluate the different approaches: (A) controlling (the specialist approach), (B) student autonomy (the generalist approach), and (C) combination strategy (autonomous/generalist and controlling/specialist). Findings confirm more autonomous/generalist approaches foster positive student experiences and outcomes, but a balance of instructional techniques is still needed. It is clear that more work needs to be done to explore engineering education in the context of fire safety engineering, and this study provides preliminary results that suggest areas for future scholarship.

1. Introduction

Although the body of knowledge around discipline-specific pedagogical approaches is growing within engineering education, fire safety engineering still remains underdeveloped. Instructors may be tempted to lean on professional standards as a guide for pedagogical approaches, but we argue that current standards are inadequate for preparing the next generation of fire engineers. The application of fire safety engineering (FSE) to building design is an area where a drastic transition between code-based standardised solutions and novel approaches has occurred in the last two decades. There has always been a significant demand for specialist engineers who can apply standardised solutions to resolve classified problems quickly and accurately. Entirely novel designs in contrast generate new problems for which standardised solutions cannot be applied or extrapolated. In this case, generalist engineers are required to first define the problems before they can develop options and if necessary, create new solutions. Current FSE education is aimed at producing specialists and therefore not fulfilling the demand for generalists in innovative architecture/engineering practices. Thus, FSE education methods need to be revisited. In sections below, we will detail the problems with fire safety engineering education as well as what is meant by generalist and specialist engineering. This research was informed by literature on problem-based learning environments, supplemented with additional well-studied approaches to learning. In this way, we seek to formally bridge fire engineering education with the broader body of knowledge in engineering education. This study is also part of a larger work to lay the foundations for a generalist FSE education programme. We aim to address the following research question: Across multiple sections of a fire safety engineering problem-based learning course, how do different pedagogical approaches shape student participation and outcomes?

2. Literature Review

2.1 Fire safety engineering and higher education

Because FSE is a relatively newly explored topic in engineering education, it is important to define the field to scope desired outcomes for students learning in FSE. Fire safety engineers are able to define the strategy for resolving fire safety issues in a variety of contexts; including the management of wild-fires, forensic investigation and modern building design. In each case, the fire engineer must have the knowledge to choose – and subsequently use – appropriate tools. Available tools include standardised codes and best-practice guidelines, computational modeling software, chemistry and physics. Fire safety engineering is the process of defining and solving safety problems related to a fire during the design process [1]. It is necessary because, in the absence of adequate fire safety engineering, any fire event will result in unacceptable damage. As opposed to other hazards, a fire event has a probability of unity [2] thus the aim of fire safety engineering is to guarantee that these events progress to unacceptable outcomes only rarely. The objective is therefore to reduce the probability of a societally unacceptable event to a socially acceptable number by managing the progression of the event. Despite the success of fire safety engineering, each year, fires still cause billions in dollars in direct losses. To achieve cost effective solutions for all design variables, including fire safety, it is therefore essential that the fire safety engineer is fully integrated in the design process and integrated into design in undergraduate education. This is currently not the case and for numerous reasons, and the fire safety industry remains one of the most prescriptive industries in the built environment [3]. Furthermore, the fire safety industry adopts a predominantly reactive approach to identifying new problems [3].

Architecture and engineering practices now have a long history of performance-based design [4] as opposed to code-prescribed design. The needs for performance-based design have been introduced into educational practices, delivering methods that address problems such as communication and integrated practice [5]. Other disciplines such as structural engineering or architecture still treat fire safety as a matter of prescription and thus interdisciplinary communication is very poor [6]. Educational practices for FSE are not necessarily consistent with the objectives of performance-based design [7]. Pedagogical research in the field has been limited to defining model curricula [2], despite the acceptance that subject-specific knowledge is only one component of education. Furthermore, the education of other disciplines designed to facilitate communication with fire safety engineers is limited to reviewing building codes.

Another way to look at the dichotomy of code-prescribed versus performance-based design is through the lens of a specialist versus generalist approach. We define an individual who prefers to focus on the acquisition and application of established knowledge, tools and methods as a “specialist”. Specialists are adept at memorising methods, rules, procedures and large amounts of detailed, often abstract knowledge. We define an individual who can see the big picture and understand and integrate available knowledge as a “generalist”. Generalists can be defined as ‘meaning seekers’ [8], ‘system architects’, ‘integrators’ [9] and ‘global learners’ [10]. Fire safety specialists apply standardised methods quickly and efficiently. Fire specialist roles include fire fighters, code consultants, computer modelers, sprinkler designers, lab technicians and regulators. Generalist fire safety professionals, in contrast, aim to assess and define unique problems and then define a custom strategy or methodology for solving them. Fire investigators, performance-based regulators and fire safety engineers are “generalist” fire safety professionals.

2.2 Characteristics of problem-based learning

The fire safety engineering course under study was designed to be a problem-based learning (PBL) experience for students. PBL is focused, experiential learning organised around the investigation, explanation, and resolution of meaningful problems [11]–[13]. PBL has been developed largely in response to the perceived shortcomings of traditional didactic teaching practices [14]. The principles of PBL are by no means new, and have been advocated by many prominent education researchers, (e.g., [15]–[18]). Other authors state that the main goals of a PBL environment are to: Increase intrinsic motivation to learn; develop self-directed, lifelong learning skills; develop effective problem-solving skills; improve effective collaboration; and expand and deepen a flexible knowledge base [11]. Students perceive the learning process to be more meaningful and relevant to them and their lives than many lecture-based programmes they have experienced [19], [20]. It has been argued that the principles of PBL are aligned with the natural process of human intuition [12], [21]. Traditional education, however, is not structured in this way [22]. The type of questions students work on in a PBL experience are unstructured, fundamentally different to the well-defined exercise questions used in traditional training [23]. In most cases, it involves substantial amounts of student self-directed learning [24]. It creates an environment in which context is established before knowledge is learned, and students actively learn whatever is deemed to be useful to the task at hand [25]. In PBL, the first role of the instructor is that of facilitator, and second as a knowledge resource [26].

Problem-based learning can improve student motivation and life-long learning skills [11]. Milà & Sanmartí [27], for example, note the improvement in transferrable skills resulting from students actively working on real and simulated problems in environmental engineering. PBL can create a more intrinsically motivating purpose, (i.e. students are naturally interested and willing to work independently). In the absence of an intrinsically motivating purpose, and/or in situations where an authority expects a specific outcome, students must be extrinsically motivated.

3. Guiding Frameworks for Analysis

3.1 Autonomy and control

A commonly held assumption is that students need to learn a certain amount of pre-defined knowledge before they are capable of self-directed learning [18], [28], [29]. One’s capacity to learn new knowledge certainly does seem to be positively linked to one’s level of existing knowledge [30]. A more contentious question is whether this knowledge must specifically be taught or whether it is possible for students to learn it autonomously. Several studies (e.g., [31], [32]) suggest that human beings have the innate ability to derive meaning from the world around them, and can learn without needing to be taught by others. Extensive research in PBL and self-directed learning would appear to support the theory that students are naturally motivated and capable of self-directed learning regardless of their initial levels of knowledge and that imposing information on them could undermine their natural motivation for learning [20], [33]. Moreover, the imposition of external constraints on an activity has been shown to undermine intrinsic motivation [34]; decrease creativity [35]; decrease critical thinking [36]; reduce performance on heuristic activities [34] and hinder personal, social, intellectual and moral development [37], [38].

The opposite of control is autonomy, and where control leads to compliance, autonomy leads to engagement [39]. The traditional assumption underlying control is that people may not be inherently motivated to learn [32], and that if they had freedom they would shirk [40]. Research has demonstrated that this is often not the case, as many people actively want to be autonomous, self-directed and individually accountable [39]. The issue about how much self-direction students should be allowed seems to have emerged as an area of conflict for many educators who feel torn between the ideals of self-directed learning and their perceived duty as responsible teachers to ensure students become safe and competent practitioners [19].

Aligned with the PBL literature, researchers have proposed that the educators' role is changed from source of knowledge to source of facilitation [23], [41]. However, learning to facilitate well is a challenge and this shift of roles and responsibilities can make some educators deeply uncomfortable [42]. The literature indicates that the way to relinquish control and support autonomy is to give students trust and responsibility over their actions [43]. Students can be given the opportunity to choose their own methods and learning resources, and even conduct their own assessment.

3.2 Intrinsic and extrinsic motivation

Individuals can be extrinsically motivated by rewards and punishments imposed by others [32]. Intrinsic motivation, in contrast, is characterised by a genuine interest in the task itself [37]. It has been shown that intrinsic motivation leads people to engage with the process, rather than simply focusing on the task goal. In industry this greatly improves productivity, and it follows that students should be equally engaged in their university work [44]. Intrinsic motivation has been shown to relate positively to cognitive outcomes [45], [46]. For example, there is a relationship between students' interest/ enjoyment (intrinsic motivation) and their subsequent recall of studied material [47]; their conceptual understanding [37]; depth of text processing [48]; behavioural persistence [49]; well-being [46], [50]; self-efficacy for learning and performance; problem-solving ability [37]; use of adaptive learning strategies; effective resource management; critical thinking; and effort regulation [45].

Extrinsically-motivated students may value grades, praise and others' perception of their intelligence and may try and achieve those goals in the quickest, easiest ways possible [51], [52]. Expending effort, particularly if that effort does not lead to success, implies a lack of ability [53]. The presence of mainly extrinsic goals may lead to unethical behaviour [54], narrowed focus [55], increased risk taking [56], decreased cooperation [57], and decreased intrinsic motivation [58].

4. Research Design

The purpose of this study is to explore different approaches to teaching fire safety engineering within a PBL setting. To this end, we addressed the following research question: Across multiple sections of a fire safety engineering problem-based learning course, how do different pedagogical approaches shape student participation and outcomes?

To address this question, our study focused on one semester and three sections of the same fire engineering undergraduate course at a large research university in the United Kingdom. Recall that these approaches were chosen for study because they align with predominating approaches to industry practice in fire safety engineering (i.e., specialist and generalist). We used multiple case study techniques [59], [60] to develop an understanding of the impact of different pedagogical approaches to this problem-based fire safety engineering course. Case studies are appropriate when the phenomenon of interest is difficult to separate from the context [59], [60].

4.1 Case construction

Cases were bound by each section of the course and the semester they were taught. The aim was to compare teaching philosophies (i.e., Group A – controlled/specialist, Group B – autonomous/generalist, and Group C – combination) to better understand what might have the greatest positive impact on student outcomes. There are ethical considerations whenever the same course will be taught differently for the purpose of educational research. It could be argued that a generalist approach prepares students for more post-university opportunities. However, there are still benefits to both approaches and arguments within education and industry as to the best methodology. Purposefully, this study was not designed as a quasi-experiment to compare a new educational innovation versus the status quo. Instead, existing approaches to learning were explored in context.

The goal for Group A was to transfer as much information as possible from the instructor to the students in a more prescriptive approach. Students in Group A were taught substantial amounts of fundamental knowledge in a clear, sequential way before being given an opportunity to apply it. The aim was to cover all the necessary fundamental knowledge outlined in the curriculum and to give students practice in applying that knowledge. The assumption was that students would then be able to use that knowledge independently later. Furthermore, it was assumed that the students would not study unless they were motivated by external factors such as grades.

The goal for Group B was to foster a learning environment where students were more intrinsically motivated and autonomous. Students in both Groups already had open-ended problem sets to work on and therefore had the possibility of an intrinsically motivating reason to learn. The Group B instructor therefore assumed that there was no need to incentivise the students to learn specific knowledge in a particular order. The assumption was that the students would naturally gravitate towards learning the fundamentals if/when they identified the gaps in their knowledge. The students were encouraged to work autonomously and build confidence in their own ability to make decisions and be self-directed. The instructor also learned the students' names to increase responsibility and accountability of each individual.

The students in Group C were taught by both the instructors from A and B. The instructors would alternate each week – taking it in turns to teach the class. The students were therefore taught using a combination of the two methods outlined above.

4.2 Course description

In case study designs, it is important to detail the study context [59], [60]. The learning goals of this course were focused on providing students the opportunity to understand, assess and predict the development of fire within a building. Based on the conclusions found from the previous year, the purpose of the course was not relayed through the lectures, but through the problem sets. The problem set questions were open-ended with the goal of creating a tangible purpose. The use of open-ended questions can be answered by students at every level, irrespective of background knowledge [61].

The problem set tasks were derived from stakeholder surveys using existing methods [62]. Through a survey, fire engineering academics at the University were able to give their opinion of what skills and technical knowledge students should learn, and to what extent.

4.3 Data collection, participants, and analysis

Consistent with case study designs, multiple sources of data were used including semi-structured classroom observations and assessment of student coursework. Observations were partially informed by the researchers' review of PBL literature and expertise in fire safety engineering, leaving room for unanticipated observations as well. In total, participants included 16 students in Group A, 21 students in Group B, 6 students in Group C and two instructors (one Group A, one Group B, both teaching in Group C). Students from multiple disciplines of engineering were represented.

Classroom observations and student data were analysed using aspects of qualitative techniques from Miles, Huberman, & Saldaña [63]. The lens of student motivation as it relates to autonomous and controlled learning environments served as a guide to help establish trends in the data. Patterns in student assessment data were determined to make comparisons in light of the interpretations of classroom observations.

Our study follows guidelines for promoting research quality [64], [65]. For example, we used triangulation among data sources, peer debriefing, and provided rich descriptions of study context to promote transferability of results. Ethical implications of data collection were considered in accordance with institutional requirements.

5. Results and Discussion

In the following sections, we detail the results of the analysis of observation and student coursework data. We discuss it in the fire safety engineering context and in light of contemporary literature in engineering education and beyond.

5.1 Controlled/specialist approach

Recall that Group A took a more controlled/specialist approach to the course. Based on classroom behaviour, students appeared more extrinsically motivated by Instructor A, who used praise to foster personal satisfaction and expectation to create fear. Still, students were very complimentary of the instructor, and greatly appreciated the breadth and depth of taught information.

Almost all the students had created solutions with the support of Instructor A and their peers prior to the lecture intended to teach those solutions, implying that the students were motivated to study. However, very few of the students answered bonus questions provided – which points to lower intrinsic motivation. Many students submitted their work to the instructor for formative assessment prior to the final deadline and were more likely to use solutions given to them by the instructor or from a textbook than create solutions themselves.

The results for Group A also suggest that students were more likely to copy from the instructor, from literature or from each other in a controlled environment, where expectation from the instructor was high. This could indicate a lack of confidence, low self-efficacy or even fear; it could mean that the students lacked contextual understanding [1], and it could imply that the students had no incentive to look beyond the supplied course material. Learners' self-efficacy – their beliefs about their own capacity as learners – has an impact on their achievement [66]. In particular, research has shown statistically significant relationships between self-efficacy beliefs and academic performance and persistence [67]. Lower self-confidence can contribute to avoidance of failure altogether [68], fear of autonomy and responsibility [69] and blind acceptance of taught information [30]. These traits are not conducive to learning in an autonomous environment, or to becoming a competent professional.

5.2 Autonomous/generalist approach

Through observation it was found that students in Group B, the more autonomous/generalist focused group, were more likely to ask questions during class. As the course progressed, the questions asked became predominantly knowledge-based (e.g., "would cancelling the viscosity term not make the result unrealistic?"), rather than administrative (e.g., "will this be in the exam?"). Such questions were indicative of deeper learning approaches and were different to the types of questions asked by students in Group A, or by any student in the class.

The students in Group B also preferred answering problem set questions that involved describing concepts, rather than completing calculations. Many of the students answered the bonus questions given in tutorials and took part in long intellectual discussions with the instructor over some of the more challenging questions. Most students appeared intrinsically motivated and interested in solving the problem set questions. Students' confidence improved over the semester, and personal interaction - with the instructor and between students – seemed to have a positive effect on motivation.

Instructor B encouraged discussion, peer tutoring, peer assessment, and working in teams. At the beginning of the semester, the students did not want complete autonomy, and actively rejected the offer of self-assessing. Students' work improved notably following formative feedback from the instructor. Many submitted their work several times prior to the final deadline. In the problem sets, the students were confident in creating solutions that they had not been taught during the course. Furthermore, many developed solutions that were better than those offered by the instructor indicating development of new solutions in line with a generalist mindset.

Students in Group B were more likely to seek their own information sources. This could indicate that the problem sets created an intrinsically motivating purpose; while the lack of information provided by the Instructor encouraged autonomy and incentivised students to develop their own answers. There are several notable benefits to autonomous learning. Like many educators, Felder and Brent [21] realised that: "nobody ever learned anything nontrivial by having someone else tell it to them" (p. 40). Much of the education literature advocates a shift towards a more student-centred (autonomous) environment [70]. Some of the reasons are given below: A study of over 6500 students found that students who were actively engaged and self-directed gained far greater conceptual understanding than students who were passive [71]; a conclusion supported by others

[46], [72], [73] attributed this increase in conceptual understanding to enhanced autonomy and internal locus of control.

5.3 Comparing autonomous and controlled approaches

In the combined approach, Group C, every student preferred to work on the problems that they had more time to think about. Some students chose to attend specific tutorial classes and were absent in others. There were several reasons why this may have been the case, but it is possible that the students were choosing to attend only the tutorials with their preferred instructional approach.

Students in Group C, as in Group B, demonstrated creativity in their responses to the problem set questions. For example, when faced with the problem of estimating the temperature profile in a large room during a fire, students realised the deficiencies of using the standard methods and came up with excellent concepts on their own. One of their ideas had only recently been proposed by a team of leading academic researchers [74].

Group B may have given too much autonomy and did not work for all students. In both Groups, students were given the information required to answer the problem sets at different times to understand how little or how much structure the students needed to illicit motivation without incurring frustration. Group A was given too much information, while Group B wasn't given enough. Information is therefore required, but the way it is presented – and the timing – is critical. Autonomous environments are not suited for all students [75]; some may not initially have the required skills for autonomous learning [31]; others simply do not feel confident enough to think critically and learn autonomously and, particularly with unskilled tutors, may feel left behind [72]. There is evidence to suggest that these students need a large amount of reassurance from tutors and peers that they are 'doing the right thing' [76, p. 58]. A certain amount of instructor-provided structure in a problem-based learning environment is important for student success [77]. Koestner et al. [34] and Ginott [78] explain that structure – lectures, information, assignments, rules etc. – can increase intrinsic motivation and work rate, provided it is offered in an informative, non-controlling way. Structure is the assembly of limits intended to support autonomous learning. Limits help learners develop a sense of what is possible in our world and our society [34]. A designer for example is unable to simply design something; they first need to set limits within which to design and innovate. Students appreciate a high degree of organisation, preparation and planning on courses, which in turn increases the likelihood that they will adopt a deep approach to learning [76]. Even students who are fully autonomous and intrinsically motivated may struggle to learn the skills and find the knowledge they need to progress, and would benefit from being shown established ideas, knowledge, tools and methods [12].

Looking across instructors, we saw that they had fundamentally different roles. Instructor A was an authority; while Instructor B was a facilitator. Students in Group A seemed to view the instructor as a valuable learning resource as they were able to give clear, detailed answers to any of the students' technical questions. Students in Group B viewed the instructor as a facilitator who created an environment where students could learn from a variety of sources. Many students found Instructor B to be a source of frustration. Table 1 presents a summary of the case findings and our interpretations.

	Group A	**Group B**	**Group C**
Pedagogical approach	Controlled/specialist approach	Autonomous/generalist approach	Combined approach
Instructor role	Authoritative/directive	Facilitative	Both directive and facilitative
Key findings and interpretations	*Extrinsic motivation *Low confidence and fear of failure *Relying on instructor, less student independence	*Intrinsic motivation *Higher confidence as course progressed *Deeper, student-directed learning	*Students gravitated towards one of the two approaches *Timely directive instruction, a balance of approaches, benefits students

Table 1: Case Summaries

5.4 Considerations of student outcomes across all groups

Summative assessment was the same across Groups and therefore serves as a useful point of comparison. It was clear that for all Groups, summative assessment had a noteworthy impact on the students as found in the previous year. The incorporation of formative assessment encouraged autonomy and was found to have a positive impact on student motivation and learning, consistent with previous research [19]. Figure 1 shows the exam grades for students on the course. The results show that students in Groups B and C, which included a large percentage of autonomy and very little structure, performed noticeably better in a summative exam than students in the highly structured environment of Group A.

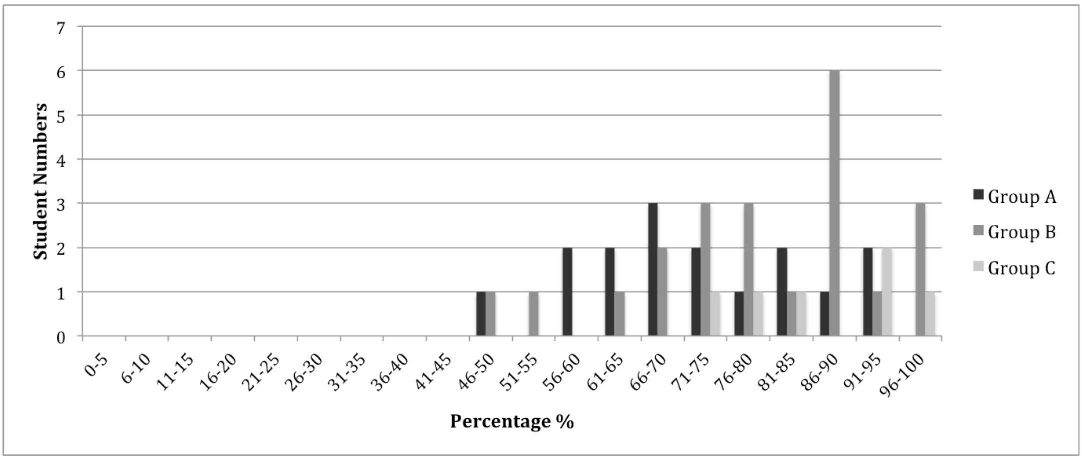

Figure 1: Exam Grades

Figure 2 shows the students ranking by their tutorial grades, with the exam grades overlaid. The graph shows the variation in the students' performance between the two forms of assessment. This graph also shows how some students can deliver consistent high-quality work throughout the semester only to perform poorly in the final 1.5 hour exam. Very few students achieved the opposite. The results align with research that states that students, through practice, can become proficient in the tasks they partake in at university, but the type of tasks offered affects how information is learned, and how it can be used in future [79]. The tasks should reflect those that would be encountered in professional practice [80], and should assume a predominant role in the teaching process [81]. For these reasons, the effectiveness of the problem sets and tutorial classes should be assessed based on their ability to illicit the types of behaviour that would be considered desirable in industry.

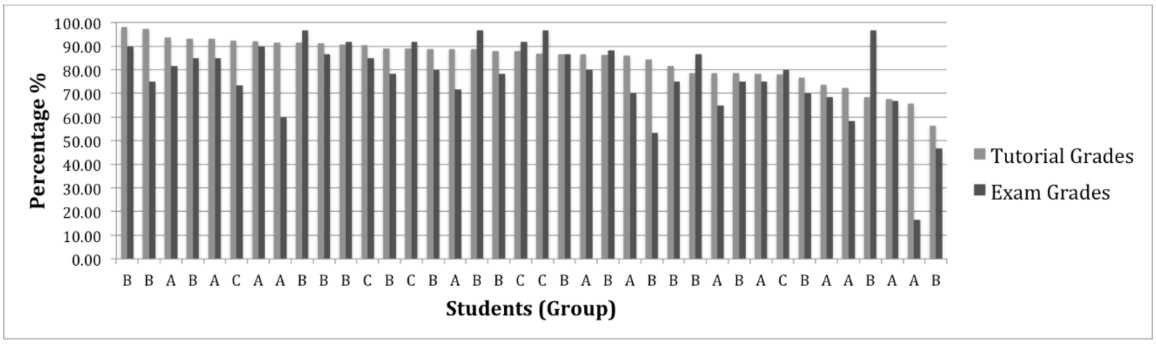

Figure 2: Exam and tutorial grade difference

Table 2 shows the average grades for each Group, including the tutorial grades, exam grades and final grade (composed of 25% coursework, 75% exam). There are several possible reasons why students in Group C achieved the highest average exam grades and it was not possible in this Group to attribute their success to just one variable. It is thought that because Group C students had 50% tutorials with Instructor A and 50% with Instructor B that both the specialist and generalist mindset was supported instead of promoting the specialist or generalist teaching with Groups A and B respectively. This may have led to the realisation that the teaching techniques used by the tutors did not suit every learner.

	Tutorial		**Exam**		**Overall**		
Group	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Std Dev**
A	80	86	73	71	75	75	13
B	85	87	79	80	81	82	11
C	87	88	86	88	87	89	7

Table 2: Average grades

6. Limitations

There are several limitations to our research design. Instructors of this course that participated in the study also served as researchers. To mitigate the potential negative consequences made possible by this overlap, interpretations were presented and checked with an additional researcher who then co-authored this publication. Because the primary source of data was from observations, some assumptions had to be made about the underlying phenomenon driving observable student behaviour. This choice was made to reduce the impact on the student experience, in line with our ethical commitments.

7. Conclusion

The main objective of this study was to develop an understanding of how varied pedagogical approaches shape student participation and outcomes in a fire safety engineering course. We compared three pedagogical approaches: (A) controlling (the specialist approach), (B) student autonomy (the generalist approach), and (C) combination strategy (autonomous/generalist and controlling/specialist). Students in a more controlled environment exhibited lower intrinsic motivation, lower confidence in their abilities and success, and tended towards more superficial learning (e.g. copying the instructor). A more autonomous environment appeared to support deeper, student-directed learning and improve confidence issues. Autonomous learning also led to greater contextual understanding of the subject material and improved students' ability to define and solve new problems, also encouraging the generalist mindset. It appeared possible to promote an intrinsically motivating purpose using open-ended problem set questions in fire safety engineering. For this to be successful, divergent questions must be supported by the structured delivery of information if they are not to become a source of frustration to students. But how and when this information is given is crucial. We conclude that a combined approach that balances techniques and provides students with timely added structure and information can suit a wider range of learners and provide preparation for industry practice in fire safety engineering. Group C was the only Group that combined approaches and the students in this Group performed very well in the exam. The combination of both autonomous/generalist and controlled/specialist learning should be pursued in future studies.

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