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Transforming a digital electronics and microcontrollers education using educational escape rooms

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ABSTRACT

CONTEXT

At times, the traditional classroom can be a place where students are disengaged and are not applying themselves collaboratively in problem solving. The educational escape room approach creates a fun, engaging learning environment were students work together in small teams to solve problems. Educational escape rooms have been demonstrated as an active learning approach to improves student engagement, intrinsic motivation and team-based problem-solving. These escape rooms have been introduced to a 3rd year subject encompassing digital electronics and microcontrollers where students were disengaged in traditional problem-solving tutorials.

PURPOSE OR GOAL

As students were disengaged during the tutorials, the aim was to create a highly engaging learning experience where students interactively solve problems with their peers to replace these tutorials. We wanted to quantify student engagement with the activities, teamwork within the activities and the extent to which students are entering into a state of flow. We also wanted to characterise the effect of effectively breaking two principles in game-based learning: marks should not be assigned and that performance rewards should not be given.

APPROACH OR METHODOLOGY/METHODS

The escape room activities were designed to follow lecture material as revision. Over four years this subject has morphed from one escape room to a total of three escape room activities, which collectively contribute to 10% of student's final assessment. The decoder boxes we use collect analytics data on student progress (time taken per puzzle and number of incorrect guesses) which we use to evaluate puzzles along with post-activity surveys and focus groups. We also note observable behavioural changes for teamwork and success during the activities.

ACTUAL OR ANTICIPATED OUTCOMES

Results show students are strongly engaged in collaboratively solving the educational escape room activities and most could reasonably be classified as entering a state of flow. Students were, to the surprise of staff, strongly in favour of escape rooms as marked activities based on team progression. The built-in electronic time penalties dissuade guessing to skip puzzles (unlike if traditional combination locks are used). Students experience a high level of intrinsic motivation to complete the activities and the vast majority said they liked the teamwork aspect of the activity.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Having observed students becoming significantly more engaged and collaboratively solving puzzles we see that escape rooms have a significant role to play – particularly in the application of knowledge to problem-solving, in teamwork and low-stakes assessment. Encouraged by these findings, along with the growing body of practice around escape rooms we look forward to integrating them into other subjects.

KEYWORDS

Digital Electronics, Game Based Learning, Educational Escape Rooms.

Introduction

Since their inception in Japan around 2007 recreational escape rooms (RERs) have rapidly spread around the world as fun recreational activities alongside more traditional recreational pursuits such as bowling, games nights or skating. RERs have seen rapid growth from approximately 22 in the U.S. in 2014 to 2350 in 2019, providing activities to satisfy family time, date nights and corporate team bonding activities (Nicholson, 2015; Wiemker et al., 2015; Dixon et al. 2021). Recreational escape rooms are live-action team-based games where participants need to solve a series of cryptic puzzles to reach a solution within a themed environment within a prescribed time period (Nicholson et al., 2015). Themes vary widely from bank heists and zombies through to prison breaks and kidnapping escapes.

Educational escape rooms (EERs) build off the concept of RERs, integrating domain-specific puzzles with team-based problem-solving, a thematic narrative and time pressure (Nicholson, 2018). Physical rooms don't scale particularly well to larger classrooms as only a relatively small number of participants can complete the escape room simultaneously (Ross et al., 2023; Nicholson et al., 2020). Furthermore, few people have a whole lot of small available classrooms or the budget to set up a whole of small classrooms as escape rooms for simultaneous groups.

In contrast to using physical rooms, most educational escape rooms use a tabletop approach. This tabletop approach may take the form of a lockbox with physical locks, an online escape room using computers, or the use of a physical electronic decoder box tool (Nicholson, 2018; Ross, 2019; López-Pernas et al., 2021). These different approaches facilitate different levels of learner immersion, teamwork and functionality required to run the escape room games.

Various studies have demonstrated that these educational escape routes have increased learner engagement and have been positive environments for engaging in teamwork and problem-solving. These activities are commonly highly rated by students, and, like other game-based learning activities almost hide that learning is going on as students are engrossed in the activity. Educational escape rooms have been used across many diverse areas including engineering and computer science through to nursing and history (Ross et al., 2021; Hacke, 2019; López-Pernas et al., 2019; Brown et al., 2019; Maher, 2022).

The context of this paper uses educational escape rooms within a third-year microcontroller and digital electronics classroom. This class covers a range of topics including digital logic, flip-flops, microcontroller interfacing, C programming, interrupts and timers. Educational escape rooms were introduced into this subject first in 2019 and have grown in number and scope since then. In this paper, we examine the application of these activities across multiple years and present lessons learned across multiple cohorts. Furthermore, this paper challenges some of the prevailing wisdom about avoiding game-based tasks for assessment and having performance-based prizes (Nicholson et al., 2020).

This paper is structured as follows: Firstly, the implementation of the escape rooms is discussed, specifically, how, and when they are used along with examples of the different puzzles applied throughout the semester. Secondly, details from student focus groups and the rationale for assessment are discussed. Finally, the conclusion section summarizes the findings of the work along with recommendations on how these activities can be more widely used within engineering classrooms.

Methodology

The escape rooms within this subject have been used, refined and recombined each year from 2019 to 2023. This section first lays out the different escape room implementations in terms of how the escape rooms were run in different years. Following this, samples from the current puzzles are included which demonstrate the breadth and level of difficulty the students are expected to solve. These escape rooms were run as revision activities, typically one to three weeks after the relevant material was explicitly taught in lectures. Students had access to all their lecture material during the escape room activity.

Escape Room Implementation

In 2019 two escape rooms were pioneered in this subject, each consisting of three puzzles as follows: Mixed Number Arithmetic, Logic Propagation, Logic Tables, C bit bashing, UART decoding, 7-Segment LEDs. These escape rooms were conducted with a second-generation decoder box consisting of an Arduino, a keypad and an LCD screen as shown in Figure 1 (left). No marks were assigned to these activities which were run during normal tutorial timeslots.

Figure 1: (left) 2nd generation decoder box, (right) 3rd generation decoder box

In 2020 three escape rooms were run each consisting of three puzzles as follows: Mixed Number Arithmetic, Logic Propagation, Logic Tables, C Bit Bashing, C Errors, C Truthtables, UART Decoding, Timer Waveforms and 7-Segment LEDs. Due to the pandemic, these activities were run using an online interface and students collaborated using Zoom. These activities were marked as follows: for each escape room students received a mark out of 5 based on the time remaining from the original 45 minutes (>15 minutes = 5/5, >10 minutes = 4/5, >5 minutes = 3/5, >1 second = 2/5, did not escape = 1/5). Students received marks for their best two out of three escape room activities which contributed towards 10% of the whole subject.

In 2021 the same three escape rooms were used as in 2020 but were conducted in class using a third-generation decoder box as shown in Figure 1 (right). In 2022 and 2023 the timer puzzle was replaced with the LCD screen puzzle reflecting some changes in the course to include LCD interfacing. The activities were marked according to the same marking scheme as used in 2020. Escape rooms from 2021 – 2023 were run in the first hour of a weekly 3-hour laboratory class as all tutorials had transitioned to online delivery.

Puzzle Implementation

This subject has grown to a total of three escape rooms comprising a total of nine puzzles. This section provides a representative sample of each of the puzzles (for brevity) to demonstrate the scope of the material covered and how different puzzles can be encoded to provide a numerical answer. The different escape room puzzles are presented in Figures 2 – 10. A different written narrative is used for each of the collections of escape room puzzles to tie each of the puzzles together and provide context for why they need to be solved.

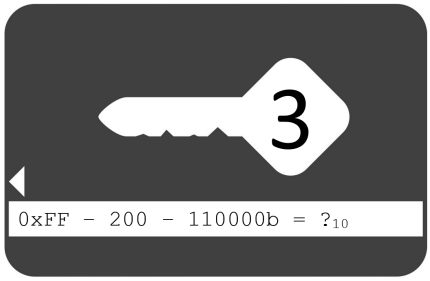

Figure 2: Mixed number base arithmetic puzzle

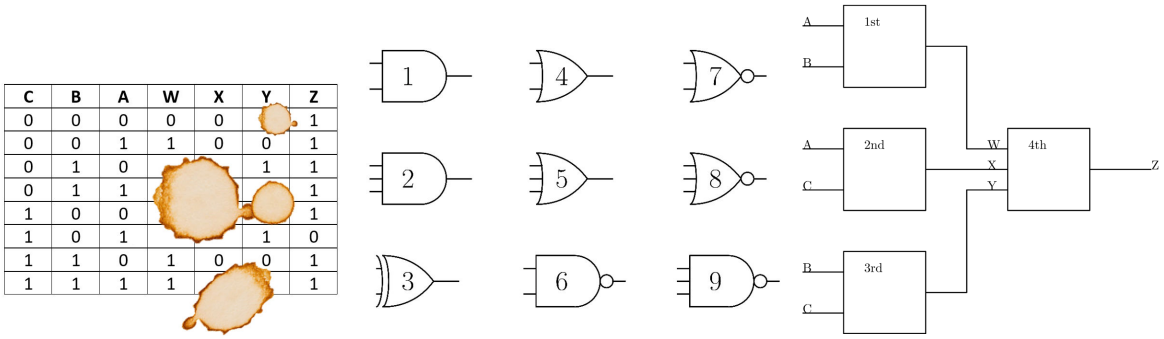

Figure 3: Logic Tables Puzzle

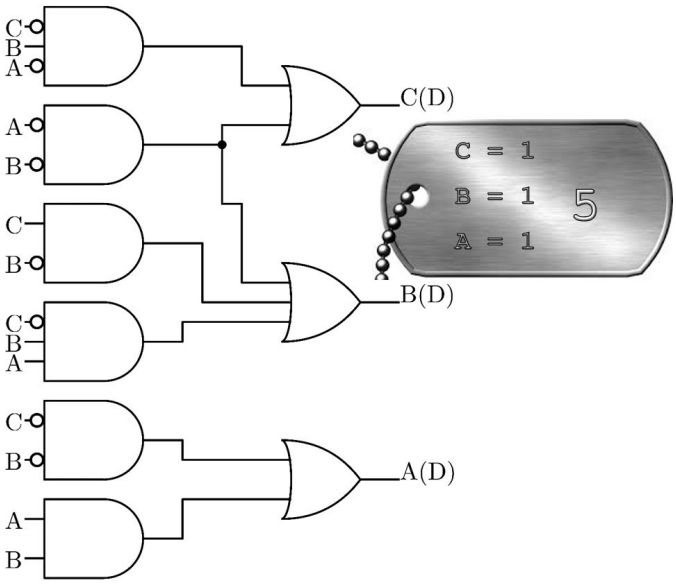

Figure 4: Logic Propagation Puzzle

```
    unsigned char num_1 = 168;
    unsigned char num_2 = 36;
    unsigned char num_3 = 70;
    unsigned char num_4 = 97;
    unsigned char num_4_mask = 36;
    num_1>>=1;
    num_2<<=1;
    num_3+=76%16;
    num_4^= num_4_mask;
    printf("Digit 3 is %c%c%c%c%c\n", num_1, num_2, num_3, num_4, num_4);
```

Figure 5: C Bit Bashing (prints out the value THREE)

```
x = (a&c)|b;    y = !((c|b)|(a&c));    z = (c|b)&(a|b);
```

a	b	c	x	y	z	#
0	0	0				
0	0	1				
0	1	0				
0	1	1	1	0	1	5
1	0	0				
1	0	1				5
1	1	0				
1	1	1				

Figure 6: C Truth tables (x, y and z need to be filled in to compute number)

```
1   for(int i = 0; i > 22; i++)
2   {
3      P1OUT ^= BIT5;
4      P2OUT &= ~(BIT2|BIT4);
5      if(i == 5){
6         i--;
7      }
8   }
```

Figure 7: C Errors (error is on line 1 as > should be <)

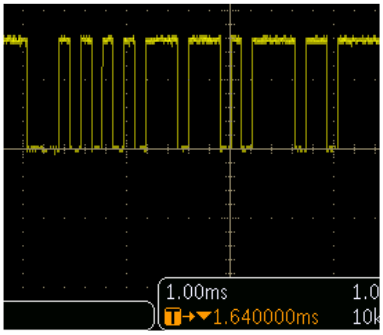

Figure 8: UART Decoding (Decodes as TWO using ASCII Table)

```
void setupTimer7(void){
  BCSCTL1 = CALBC1_8MHZ;
  DCOCTL = CALDCO_8MHZ;
  TACTL |= 0x0210;
  TA0CCR0 = 210;
  TA0CCR1 = 105;
  TACCTL0 = 0x00;
  TACCTL1 = 0x60;
  P1SEL |= BIT6;
  TACTL|=0x0010;
}

void setupTimer3(void){
  BCSCTL1 = CALBC1_1MHZ;
  DCOCTL = CALDCO_1MHZ;
  TACTL |= 0x0210;
  TA0CCR0 = 300;
  TA0CCR1 = 150;
  TACCTL0 = 0x00;
  TACCTL1 = 0x60;
  P1SEL |= BIT6;
  TACTL|=0x0010;
```

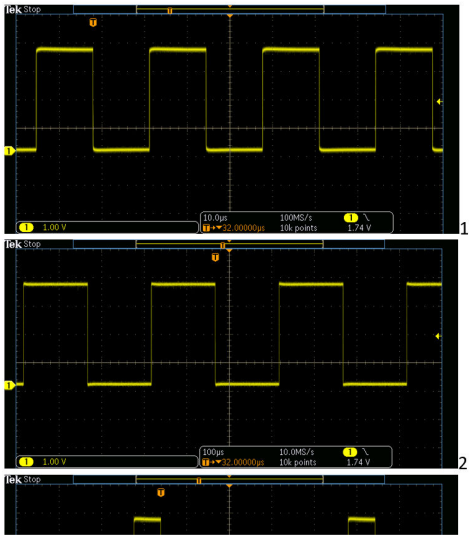

Figure 9: Timer Waveforms (different timer setups matched to different waveforms)

```
LCD_Write_CMD(0xCC);
LCD_Write_DATA(0x4E);
LCD_Write_DATA(0x69);
LCD_Write_DATA(0x6E);
LCD_Write_DATA(0x65);

LCD_Write_CMD(0x86);
LCD_Write_DATA(0x53);
LCD_Write_DATA(0x69);
LCD_Write_DATA(0x78);
LCD_Write_DATA(0x2D);
LCD_Write_DATA(0x3E);

LCD_Write_CMD(0xC1);
LCD_Write_DATA(0x53);
LCD_Write_DATA(0x69);
LCD_Write_DATA(0x78);
LCD_Write_DATA(0x2D);
LCD_Write_DATA(0x3E);
```

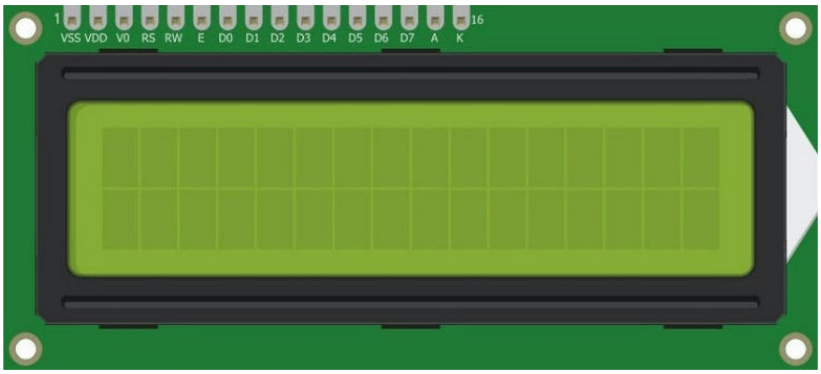

Figure 10: LCD Screen Writing (writes out various numbers on the screen in different positions)

Key 4: P1Out = 0xD4

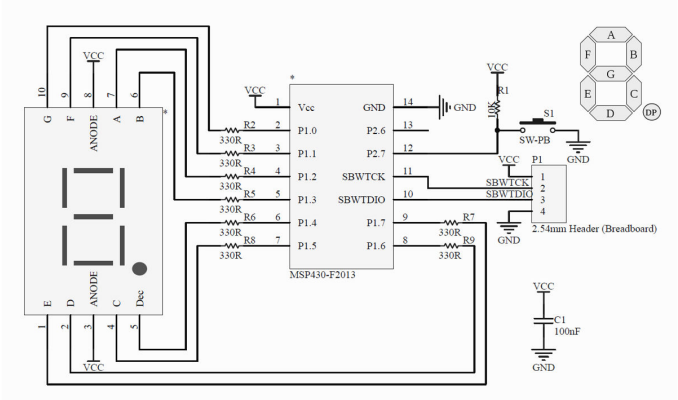

Figure 11: 7-Segment Display (displays the number 4)

Results and Discussion

Previous studies have shown strengths of escape rooms related to engaging students, encouraging teamwork and applied problem-solving (Veldkamp et al., 2020). This section reflects to the degree that each of these have been present through student observation, focus groups and quantitative data.

In terms of observational results, the in-person escape room activities have almost exclusively contained highly engaged students. Most groups have tended to work together to unlock the main idea behind each puzzle before allocating different parts of the puzzle to different team members to solve (to help with a division of labour). One interesting social dynamic has been around the relative appetite of different students for guessing. As incorrect guesses have been penalised with a 1-minute time penalty, most students have been deterred from guessing unless they were stuck between only a few different options which has occasionally resulted in some disagreement about when it was appropriate to make a guess.

Feedback from an early escape room activity run with staff (in 2018 before running any of these escape rooms in the classroom) provided some insightful results. Several staff felt that the questions were too difficult for students and that students would be strongly opposed to these being marked activities (Ross et al., 2021). In response to difficulty (which was based on the UART decoding, C Bitbashing and 7-Segment LED puzzle) the puzzles were tweaked to remove some ambiguity (e.g. octal number bases were replaced with hexadecimal) and automated clues were implemented to help students when they were stuck.

The suggestions from staff related to not having this as a marked activity were in-line with conventional wisdom related to game-based learning for two reasons. Firstly, that participants should not be compelled to participate but should want to participate. Secondly, awarding marks related to performance may result in participants skipping some sections of the activity (e.g. testing values on a combination lock).

In contrast to staff opinions on what they thought students would want, post-activity focus groups with students have found students have been strongly in favour of using escape rooms as marked activities – provided the marking wasn't a large proportion of their overall assessment. In repeated focus groups students have reported they are very happy with the 10% overall contribution to their grades but a handful of students questioned if the number of minutes remaining was the best way to assign grades. Students were asked but didn't have any ideas for an alternate marking system for how grades could be assigned.

Concerning rushing through and trying to skip steps, the built-in penalties applied by the decoder box for incorrect guesses dissuade students from guessing and skipping steps. About compelling students to participate in the educational escape rooms previous publications have recorded high levels of intrinsic motivation and flow both for marked and unmarked escape rooms (Ross et al., 2021, Ross et al., 2023). Besides the relatively small number of marks a box of chocolates was given to the winning team for each escape room.

Figure 12 shows there is a relatively weak correlation between the student's final mark and the mark they scored on the escape room activities. This weak correlation is likely to have multiple contributing factors. Firstly, the activities are team-based activities, and all team members receive an equal mark. Hence, teams composed of students from both high and lower-achieving categories are likely to perform quite differently to groups all from high-achieving or lower-achieving categories. Secondly, the escape room is a low-stakes assessment which may help students uncover areas of confusion or where they lack competence that they can address before future assessments (e.g. the exam). Thirdly, as the marks are a sum of the top two escape rooms (with the lowest score dropped) the performance of the lowest escape room is not correlated (although the change is marginal). Finally, the escape room activities only collectively contribute 10% to the overall assessment, hence, some students may view this as relatively unimportant.

Data analytics collected from the boxes indicates that over the five years on only 15 occasions did a student (as part of a team of students) not escape within the 45-minute time frame from a total of 201 students participating. Hence, most students were able to complete the activity within the allocated 45 timeframes.

Immediately following the activity students have been routinely surveyed using 5-point Likert questions on aspects related to flow, motivation, engagement and teamwork within the activity (Table 1). These surveys were conducted in accordance with our approved human ethics application. Interestingly the biggest variances in these data are between the two fundamental modes of delivery – in 2020 with the online delivery compared to the other years with face-to-face delivery. As puzzles were changed and further developed over time, Table 1 aggregates available data across all escape rooms.

Question 1 addresses student motivation related to if they wanted to complete the puzzles. The students who completed this face-to-face tended to rate this more favourably and from free-text fields seemed to experience less frustration around trying to communicate effectively with their team and having the puzzles more readily at hand (in paper form rather than on a screen which was more difficult to annotate).

Question 2 relates to the extent that students may have experienced flow during the activity. The online and face-to-face cohorts had a very similar average result for this question, suggesting that both modalities allow a majority of students to experience some flow. What it doesn't quantify is how long they may have experienced this. Potentially, other elements like props or background sound effects could be used (more easily for face-to-face) to enhance emersion and possibly increase flow.

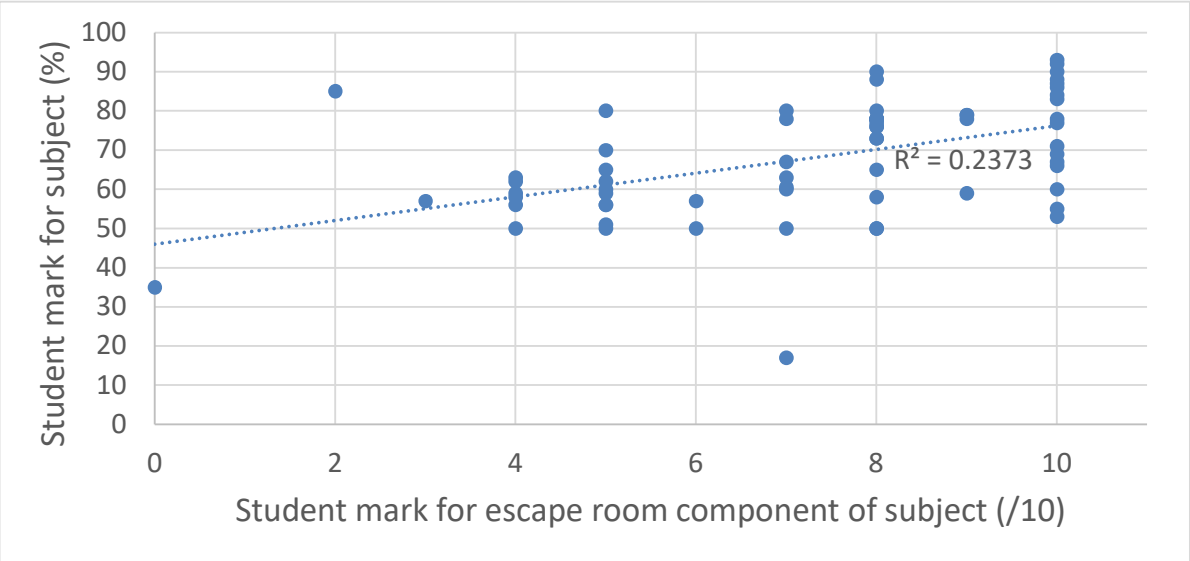

Figure 12: Student escape room marks contrasted with final marks

Table 1: Likert survey questions

	Face to Face (n=71)	Online (n=34)
Q1: I wanted to complete the escape room activity?	4.8	4.4
Q2: I became unaware of my surroundings while doing the escape room activity?	4.0	3.9
Q3: I liked the teamwork aspect of the activity?	4.7	4.2

Question 3 addresses the teamwork element of the activity. Students ranked their appreciation of teamwork significantly higher for the face-to-face activity compared to the online activity. Observationally, students sitting together around a table were seen to experience social pressure to participate (it is rude to sit back in ignore your team when they are in the same room) and almost always would do so. In contrast for the online escape rooms, some students were observed to be logged in but did not participate or engage.

Overall, the activities have been very well received by students and have been highly rated in end-of-semester student feedback forms. In contrast to some of the less engaging problem-solving tutorials that were previously conducted within this subject, these activities have high student engagement, observationally show evidence of peer learning and show students to be more highly motivated to succeed.

Conclusion

Educational escape rooms are rapidly expanding to engage students in collaborative problem-solving tasks in a fun and low-stakes manner. Although students may be strongly tempted to cheat and skip problem-solving tasks with the more traditional combination lock approaches, the educational escape rooms applied in this course dissuade this through automated penalties (time-deduction). After 5 years of escape rooms within the subject students still report they are keen for these as a marked activity, to the original surprise of the researchers and other academics. To ensure that this marking is fair, play testing needs to be conducted to ensure that puzzles are mature enough to be considered for assessment as corrections or errors mid-way are likely to degrade student enjoyment of the activity – especially if it is marked.

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