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# Ways of incorporating active learning experiences: an exploration of worksheets over five years in a first year Thai physics courses

**A Eambaipreuk[1,*], K Arayathanitkul[1], N Emarat[1] and M D Sharma[2]**

[1] Department of Physics, Faculty of Science, Mahidol University, Bangkok 10400, Thailand
[2] SUPER, School of Physics, The University of Sydney, NSW 2006, Australia

E-mail: eam.arunee@gmail.com

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**Abstract**

It has been established that the incorporation of active learning experiences in the context of university lectures increases overall student learning. This study contributes to the literature by examining iterations of incorporating interactivity where the 'intensity', in terms of the content, structure and time spent on different in-class activities is varied. The study described in this paper deals in some depth with the use of worksheets during lectures on the topic of circular motion. The study was done with a total of 1405 students studying first-year physics over five years at Mahidol University, Thailand. Over these years, the style of the worksheets as well as the in-class activities were modified. In the first year, the worksheet contained a subsection for note taking as well as problem-solving practice; in the second year, a problem-solving strategy was introduced; in the third year, a lecture demonstration with associated free-body diagrams was included; in the final two years, these diagrams were modified. There was a statistically significant difference between student performance on an examination question of circular motion between the first-year cohort and the cohorts of later years. However, the results for later years indicate a saturation of mean scores. This saturation level needs to be further investigated under different topics, with different cohorts and with different types of active learning.

* Author to whom any correspondence should be addressed.

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Keywords: active learning, free-body diagrams, Newton's second law, problem-solving strategy, worksheets, note taking, circular motion

(Some figures may appear in colour only in the online journal)

## 1. Introduction

Two decades of effort has established the efficacy of active learning experiences in assisting student learning (Hake 1998, Tanahoung *et al* 2009, Wieman 2014), with calls to investigate different types of active learning and the intensity of that learning (Freeman *et al* 2014). However, to our knowledge, to date, the response to Freeman's call has been minimal, if any. We seek to address this gap in the literature. Particular 'types' of active learning, from online polling to just-in-time, can be selected to capture the students' attention, leading them to 'think and apply', 'hands-on and minds-on', both conceptually and in problem solving (Redish 1994, Hake 1998, Novak *et al* 1999, Wutchana and Emarat 2011). A popular, low-cost and relatively easy to implement way of facilitating active learning is the worksheet (Biehler and Snowman 1986, Mihas and Gemousakakis 2007, Konrad *et al* 2009); the worksheet is the subject of this study.

Active learning can differ in content, structure and time spent on different in-class activities; this is what Freeman *et al* (2014) described as the 'intensity' of the active learning. Often there is significant variation in intensity. At one extreme, we have note taking in lectures. Research for around half a century has shown that the act of taking notes requires specific cognitive processing. Thus, taking notes is better for learning than simply having notes (Carter and Van Matre 1975). More recently, Mueller and Oppenheimer (2014) have shown that longhand note taking is better for learning than laptop note taking. Three specific cognitive processes are important: transcription fluency, verbal working memory and identifying main ideas. Of these, transcription fluency is a significant predictor of test performance (Peverly *et al* 2007). Note taking is inherently an individual activity, but note taking can sharpen cognitive processes with the potential to influence performance. Using strategies that require behavioral, social and emotional engagement (Sinatra *et al* 2015), note taking can enter the realm of active learning, albeit of low intensity. In particular, the lecturer can introduce a level of interactivity and make use of peer discussions to identify main ideas on a worksheet where note taking occurs. Collaborative note taking modifies the in-class activities and the development of the student's transcription fluency is facilitated. Note taking is still scaffolding students through steps of the process via the worksheet, but it is done in a free-flowing discursive manner with peer and whole-class discussions interspersed with questions and summaries by the lecturer (Mayo *et al* 2009, Narjaikaew *et al* 2009, Wutchana and Emarat 2011).

The content and structure of the lecture can be modified to provide class time to focus on student understanding or on problem solving by using strategies such as polling, think-pair-share and predict-observe-explain demonstrations, invoking 'hands-on and minds-on' learning (Sokoloff and Thornton 1997, Sharma *et al* 2005, Wattanakasiwich *et al* 2012, Georgiou and Sharma 2014). In all of these endeavors, worksheets are constructed and used to optimize student learning and performance (Duit 2000, Duit *et al* 2012, Sujarittham *et al* 2016). The creation of in-class activities and crafting how to facilitate active learning using worksheets normally takes several iterations and can become an ongoing process.

A pair of lecturers at Mahidol University in Thailand have been using worksheets for over ten years to facilitate active learning in their large lecture groups of first-year students studying physics. Those worksheets were collaboratively prepared in the pursuit of improving student understanding and engagement. The story of this pair of lecturers purposefully collaborating is in itself an uncommon occurrence, not often articulated in the literature. Such collaborations are found to be important and often underpin sustained improvements in teaching and learning (Sharma and Georgiou 2017, Sharma *et al* 2017). This paper presents the story of how the pair's use of worksheets and in-class activities to facilitate active learning on the topic of circular motion amongst science students evolved over five years. In all versions of the worksheets, note taking was retained as a distinct subsection. We provide an in-depth description of the changes over five years in content, structure and time spent on aspects of in-class activities (intensity) facilitated by worksheets and an investigation to see if those changes in intensity made a difference in student performance in various tests.

## 2. Method

### *2.1. Context—course, lecture style and sample*

Our research, to date, affirms the efficacy of worksheets for facilitating active learning and improving students' learning (Narjaikaew *et al* 2009, Wutchana and Emarat 2011, Sujarittham *et al* 2016). This study is a description of one particular venture documenting 'the ways of incorporating active learning experiences' and seeking to shed light on the question, 'how much is enough?'. The course is an introductory calculus-based physics course that covers mechanics, thermodynamics, waves and optics in the first semester. The course uses a textbook written by the lecturers (Emarat *et al* 2012) as well as other suggested textbooks available in the library. The course is lecture based with regular homework. There are no tutorials or recitation sessions. Another parallel but different course covers the laboratory component.

The pair has developed an interactive team-teaching style, where each has a specific role. One stays at the front of the class, maintaining oversight, keeping track, ensuring important ideas are covered, directing the class to write on their worksheet and writing on transparencies as needed. The other lecturer walks up and down the aisle, interacting with the students, providing explanations when asked by individual students or groups of students, prompting students to talk to each other and involving students in whole class discussions. At times, they have a conversation with each other across the lecture hall on key ideas, including common inconsistent ideas. Together, they orchestrate the whole class, focusing on asking questions, guiding discussions, collaboratively identifying main ideas and engaging students in transcribing.

Worksheets are handed out with the expectation that students will write ideas, concepts, equations and attempt questions on the worksheet. In essence, the worksheets require students to solve simple problems on their own, then compare and discuss their answers with their peers and, under the guidance of the lecturers, modify them as needed. With more difficult problems, students would discuss them with their peers first or sometimes solve the problems collaboratively. With some problems, the lecturer at the front would show the whole class how to solve the problem. Consistently, students were encouraged not to delete their own solutions, but to keep alternative solutions so they could compare them when revising. Every so often, they would collaborate or check-in their transcriptions with their peers.

This study is the story of this pair of lecturers, using their style of interactive teaching with worksheets to facilitate active learning over five years on the topic of circular motion, the fourth lecture of their particular Mechanics course. The numbers of students enrolled in the science program, from year 1 to year 5, respectively, were 287, 273, 287, 270 and 288.

### *2.2. Pre-test, post-test, examination question, scoring and analysis*

The measurement instruments in exploratory studies such as these need to serve the purpose of identifying trends. Our aim was to probe student performance when the style of lectures on the topic of circular motion was varied. We focused on students' understanding and how their understanding was utilized in solving problems. The research was based on the data provided by the students in their answers to a pre-test, post-test and to a question in their examination. The same tests and processes were used each year: a 10 min supervised pre-test before the lecture, a post-test at the beginning of the next lecture and an examination question on the topic. All tests were taken individually by each student in a hall, with several staff supervising. The pre-test and post-test had the same question, shown in appendix A. A similar question, also shown in appendix A, was used in the examination. The tests and examinations were administered and collected. They were not released, so students in following years did not have prior access to them.

Scoring of the pre-test, post-test and examination question occurred as follows:

0 = no answer provided or the answer does not relate to the question.

1 = concepts and/or variables relevant to the question are listed, but no attempt is made to answer the question.

2 = concepts relevant to the question are used in attempting to answer the question, but not applied consistently in solving the problem.

3 = concepts and variables relevant to the question are used in attempting to answer the question and the process is predominantly correct, perhaps with simple slips or errors.

A mark of 1 was added to any of the above for a correctly drawn free-body diagram. Hence, a total of 4 was possible by satisfying the third criterion and drawing a correct free-body diagram.

The mean scores of the pre-test, post-test and examination question were compared for the five years. First, the data were perused to identify instances of incomplete or 'obviously silly' responses. None were found and all data were retained. Second, graphs with standard errors of the mean marked as 'error bars' were plotted. Third, the data were checked to see which assumptions of the various statistical approaches could be satisfied, informing which statistical test to conduct. Levene's test for homogeneity of variance showed that at $p = 0.01$ the assumption of equal variances was satisfied for only the scores on the examination question. Hence, one-way Welch's ANOVA was conducted for pre-test and post-test and one-way ANOVA for examination scores. Finally, the Bonferroni correction, regarded as a conservative test to avoid false positives, was used when undertaking multiple comparisons of means.

## 3. Changes in 'intensity' over the five years

First, the science content of circular motion was examined to probe what was being taught. Textbooks were surveyed and analyzed (Hewitt 2002, Giambattista *et al* 2006, Knight 2008) to extract what content should be presented. The lecturers' notes were analyzed to complement the analysis of the textbooks. It was decided that the essential content was as follows:

- the identification of circular motion,
- variables such as $\Delta\theta$, $r$, $s$, $\omega$ and $v$,
- acceleration and Newton's laws—problem solving in uniform and non-uniform circular motion.

This content was kept consistent over the five years of study.

Second, research on teaching and learning in this field was examined to probe evidence-based approaches for the topic of circular motion. The literature points to the use of free-body diagrams and representations such as graphs, diagrams and mathematical equations (e.g. Court 1999, Roberts *et al* 2008, Hill *et al* 2014). The research on circular motion showed that free-body diagrams could help interpret the situation in terms of mathematical equations (Sherwood 1971, Berg and Brouwer 1991). The major conceptual struggle was with linking Newton's laws with the forces acting on bodies and how a centripetal force and consequent acceleration is produced (Stinner 2001). Further research links multiple representations, free-body diagrams and problem solving; for example, see Rosengrant *et al* (2009), Savinainen *et al* (2013) and Hill and Sharma (2015).

In year 1 of the study, an independent observer recorded the students' and lecturers' activities. The worksheet used in year 1 is shown in appendix B. Items 1, 2 and 3 of the worksheet form a subsection on note taking requiring 30 min of class time and covering concepts and equations as well as some examples. This section consisted of headings, some basic information and diagrams, with a focus on explaining the content listed above. There was missing information and blank spaces for students to take notes. Items 4 and 5 were devoted to in-class problem-solving practice taking another 30 min of class time. The observations were used to seek answers to questions such as the following: how was the existing worksheet used? What were the students doing? Were student difficulties articulated in the literature evident? One of the observations pertained to the design and evaluation of the teaching and learning environment. Particular attention was paid to time spent on each activity and the sequence of the activities. These answers give a measure of the 'intensity' of the active learning experiences being facilitated through the use of worksheets.

A summary of the observations, which informed how the authors decided to make modifications, is as follows. For the note-taking subsection, the lecturers interacted with each other and the students as described earlier, creating a free-flowing conversational atmosphere. During peer discussions, students were asked to check-in on each other's worksheets, while during whole-class discussions students were sharing and extending prior understanding. For the in-class problem-solving practice, students were spontaneously checking-in on each other's worksheets as they struggled to make sense of the content. Both lecturers walked around the class giving time for students to work through the problems with their peers, fielding questions and dropping hints but refraining from providing too much scaffolding. The observation was made that students struggled when it came to applying content from note taking in problem solving (Rosengrant *et al* 2009, Savinainen *et al* 2013); this informed the modifications in year 2. The worksheet with a subsection, which is identified in the literature as note taking combined with in-class practice, was used to facilitate relatively low-intensity active learning. Table 1 shows the structure, sequence and time spent in year 1 and in subsequent years for the lecture class time of 80 min.

In year 2, the structure was changed with the addition of a new element immediately after the subsection note taking: a problem-solving strategy combined with a 'worked example' taking 30 min of class time, see table 1. This modification was based on the observation in year 1 that students struggled with problem solving. The five-step problem-solving strategy, shown in figure 1, was outlined by the lecturer at the front of the lecture hall. The lecturer then showed them a problem, explained it and gave students time to discuss the problem-solving strategy with their peers. The lecturers then proceeded to illustrate how the problem-solving strategy could be used by solving the problem while talking through what they were doing—a 'worked example'. Student discussions, questioning and answering, as well as whole-class discussion occurred during this process. In the next 20 min, the students applied themselves to the same two in-class problems as in year 1, and in the same manner. The observation that students struggled with identifying and drawing forces on a free-body diagram (Sherwood 1971, Berg and Brouwer 1991, Stinner 2001) informed the modifications in year 3. All in all, in year 2,

**Table 1.** Structure, sequence and time spent on various in-class activities from year 1 to year 5, not showing the 10 min for the pre-test in years 2 to 5

| Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|
| Note taking 30 min | Note taking 30 min | Note taking 30 min<br>Demonstration + 1 FBD question 10 min | Demonstration + 5 FBD[a] questions 15 min<br>Note taking 30 min | Demonstration + 5 FBD questions modified 15 min<br>Note taking 30 min |
| In-class problem-solving practice 30 min<br>Finished early | Lecturer outlines five-step problem-solving strategy with no diagram | Lecturer discusses five-step problem-solving strategy with diagrams | Lecturer discusses five-step problem-solving strategy with diagrams | Lecturer discusses five-step problem-solving strategy with diagrams |
| | Worked example using the strategy 30 min<br>In-class problem-solving practice 20 min | Worked example using the strategy 20 min<br>In-class problem-solving practice 20 min | Worked example using the strategy 15 min<br>In-class problem-solving practice 20 min | Worked example using the strategy 15 min<br>In-class problem-solving practice 20 min |

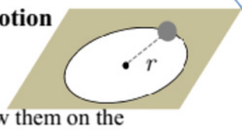
[a]FBD = Free-body diagram

more was expected of the students as a different type of engagement was utilized, making use of the worksheet to facilitate active learning, making it more intense.

In year 3, the structure of the lectures was changed with the addition of yet another new element immediately after note taking: a demonstration with a free-body diagram question. This modification was based on the observation in year 2 that students struggled with identifying and drawing forces on a free-body diagram. The demonstration was created collaboratively by the lecturers and a student volunteer. The student walked in a straight line, the lecturer held the student's arm, exerting a force and the student turned around in a circle while the lecturer rotated. During this demonstration, the lecturer asked questions. The student answered by describing the force they 'felt' and why they were turning. The other lecturer asked questions and provided explanations from the perspective of the students watching and vicariously engaging. The interaction was used to seed a discussion of forces, directions and how to draw free-body diagrams. A free-body diagram question on the worksheet accompanied the demonstration. Around 10 min were spent on the demonstration and free-body question. This was followed by 20 min on the five-step problem-solving strategy. The strategy had been modified slightly based on well-known textbooks (Hewitt 2002, Knight 2008) and validated by experts. The first three steps of the strategy were emphasized in the discussion as these are shown to be particularly helpful (Eambaipreuk *et al* 2015). Last, the students did in-class practice problems as in the previous years. The observations showed that the students were more adept at problem solving and that the demonstration, combined with free-body practice, was useful. However, it was noted that many students still struggled with the detail necessary for actually drawing, using and interpreting free-body diagrams (Court 1999, Hill *et al* 2014), informing the modifications in year 4.

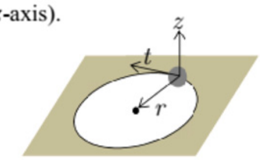
**Problem-Solving Strategy for Circular Motion**

1. Draw circular path of an object and identify its radius ($r$).




2. Draw free-body diagram: identify all the force(s), and show them on the diagram.

3. Choose perpendicular axes at the point of interest and find the force components; tangential axis ($t$-axis), radial axis ($r$-axis), and perpendicular to the plane of motion ($z$-axis).




4. Apply Newton's second law;

$r$-axis; $\sum F_r = ma_r$ ; $a_r = \frac{v^2}{r} = \omega^2 r$

$t$-axis; $\sum F_t = ma_t$ ; $a_t = \alpha r$

$z$-axis; $\sum F_z = ma_z$ ; $a_z = 0$ for unchanged plane of motion

5. Solve for the result and check that your answers have the correct units.

**Figure 1.** Problem-solving strategy in the circular motion worksheet used to facilitate active learning. Version used in year 2 had no diagram while those used in later years had diagrams. In years 3 to 5, steps 1 to 3 were emphasized.

In year 4, the structure was changed by reordering the sequence of activities: modification based on observations in year 3. Since the lecture before had discussed free-body diagrams, and given the observation that students continued to struggle with these diagrams, the demonstration and free-body question were placed at the beginning. The demonstration, still conducted in the same interactive manner as in year 3, came first, followed by a set of five questions in which students needed to draw free-body diagrams; see table 1. For the first two free-body diagram questions, the lecturers identified the path of the motion and radius as well as the magnitude and direction of the forces acting on the object. The particular technique was constructed based on methods in textbooks and other literature (Hewitt 2002, Giambattista *et al* 2006, Knight 2008, Mazur *et al* 2015). Emphasis was placed on steps 1 to 3 of the five-step problem-solving strategy without explicitly referring to the strategy. The students were then asked to discuss the remaining three free-body diagram questions with their peers and the lecturers guided the students with whole-class discussion, questions and answers. The time for the demonstration and full free-body diagram was increased to 15 min. Next, there was 30 min of note taking, as in previous years, culminating in the application of Newton's second law to the three axes. This was followed by the discussion of the problem-solving strategy and an accompanying worked example similar to previous years but with a reduced time of 15 min. The last 20 min were spent on the in-class practice, which included the consideration of the force needed to make the object move in a circular path—centripetal force.

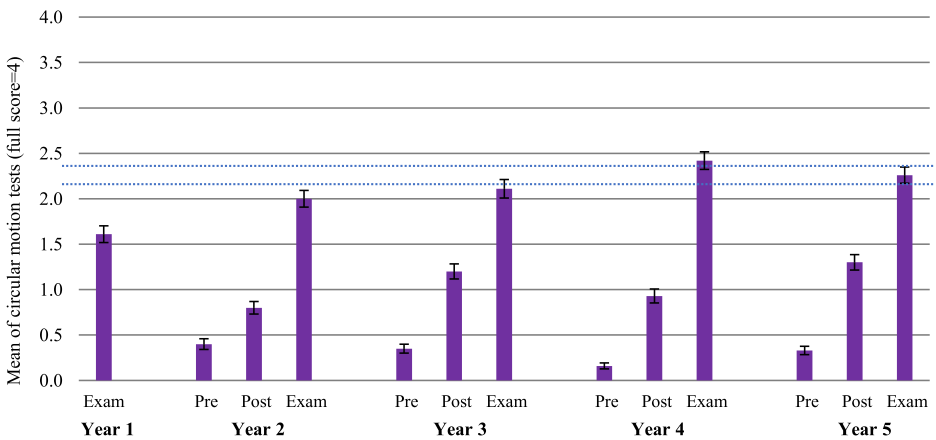



**Figure 2.** Mean score on pre-test and post-test for years 1 to 4 and mean score on the examination question from years 1 to 5. Error bars represent the SEM. Dashed line illustrates the saturation level within the bounds of the SEM.

The worksheet used to facilitate active learning in year 5 is presented in appendix B. It is much the same as that used in year 4, starting off with the demonstration, item 1. Minor modifications were made to the manner in which the free-body diagram questions, item 2, was undertaken. Items 3 to 6 constituted note taking with clear articulation of Newton's second law, followed by the problem-solving strategy, item 7 and in-class practice, item 8. There is a stark contrast between the worksheet for year 1 with that for year 5. There is not only more scaffolding, but more collaborative and interactive elements utilizing prompts on the worksheet.

## 4. Results and discussion

In this section, we point to key findings visible graphically and supported by statistics and follow this with a discussion on 'intensity' in the context of using worksheets that include a distinct subsection on note taking for facilitating active learning.

### *4.1. Comparison of pre-test, post-test, examination question scores*

Figure 2 shows the mean examination scores from years 1 to 5 and mean test scores for years 2 to 5. The error bars represent standard errors of the mean (SEM). We note substantive differences between the post-test score and examination score, which we hypothesize is likely due to students having time to consolidate their learning. Furthermore, none of the other features in the course and its teaching had changed. The combination of these would give rise to a consistent difference from year to year. Appendix A shows the questions; they are similar in form, but the examination question is more nuanced. It is appropriate to note the trend of increasing mean examination question scores with the suggestion of a saturation level, albeit with variations.

The first decision was regarding which statistical approach to use when comparing means. As mentioned previously, one-way Welch's ANOVA was used for mean pre-test and post-test scores, revealing a statistically significant difference between groups, *Welch's* $F(3{,}605) = 6.26$, $p < 0.001$ and *Welch's* $F(3616) = 7.75$, $p < 0.001$, respectively. One-way ANOVA was used for mean examination question scores, again revealing a statistically significant difference between groups, $F(41\,405) = 11.94$, $p < 0.001$. Post hoc comparisons were conducted using the Bonferroni correction and are presented below. Descriptive statistics and the results of the statistical tests can be found in appendix C.

For the pre-test scores, post hoc comparisons using Bonferroni correction indicate that means scores for both year 2 ($M = 0.40$, SD $= 0.96$) and year 3 ($M = 0.35$, SD $= 0.82$) are statistically significantly higher than year 4 ($M = 0.17$, SD $= 0.55$) at $p < 0.05$. We note that the mean pre-test score in year 4 is anomalously low. For the post-test scores, post hoc comparisons using Bonferroni correction indicate that the mean scores for year 2 ($M = 0.80$, SD $= 1.14$) are statistically significantly lower than year 3 ($M = 1.20$, SD $= 1.39$) as well as year 5 ($M = 1.30$, SD $= 1.44$). We note that the year 4 ($M = 0.93$, SD $= 1.25$) cohort, which came in with the lowest pre-test scores, is not statistically significantly different to the others at $p < 0.05$.

Figure 2 shows that the mean examination question score for year 1 does not fall within the limits of the SEM of the other years. This is confirmed by the post hoc comparisons using Bonferroni correction at $p < 0.05$; year 1 ($M = 1.61$, SD $= 1.55$) is statistically significantly lower compared to all other years, year 2 ($M = 1.99$, SD $= 1.51$), year 3 ($M = 2.11$, SD $= 1.72$), year 4 ($M = 2.42$, SD $= 1.59$) and year 5 ($M = 2.26$, SD $= 1.50$). We note that there is overlap of SEM between years 2 and 3, years 3 and 5 and years 4 and 5, while years 2 and 4 clearly have no overlap. Post hoc comparisons return a statistically significant difference between years 2 and 4 at $p < 0.05$ and no statistically significant difference between years 3, 4 and 5. The dashed lines in figure 2 illustrate the bounds of the SEM capturing this effect—the saturation of the mean examination question scores.

We conclude from these data that there is a trend for improvements as the intensity increases, but when examined statistically, there is a saturation level. This supports the conjecture that introducing more active learning combined with scaffolding or rearranging the activities has not really had an effect on the mean examination scores beyond a certain level. It should be remembered that the class time in year 1 was shorter. We note that year 4 came in with the lowest mean pre-test scores and exhibits no statistically significant difference in examination scores compared with those for years 2 to 5.

### *4.2. 'Intensity' of active learning in the context of worksheets with a distinct subsection on note taking*

There is substantial literature on the effectiveness of note taking in lectures, with Mueller and Oppenheimer (2014) showing that longhand note taking offers particular advantages for learning while Peverly *et al* (2007) point to the importance of the identification of main ideas and transcription fluency. In this study, the identification of main ideas as well as checking-in on transcription fluency with peers is orchestrated by the pair of lecturers in a collaborative manner, sourcing the students' prior knowledge and bouncing ideas around in peer groups with whole-class interactions (Mayo *et al* 2009, Narjaikaew *et al* 2009), making the learning more active.

While the act of inserting a worksheet does not predicate active learning it can form the backbone for structuring the content, pacing and time keeping so that time and space are available for scaffolding as well as for the students' sense making. In short, it makes it easier for the lecturer to identify when they need to simply remain quiet. This is not dissimilar to the worksheets used in interactive lecture demonstrations with clear demarcations for different activities (Sokoloff and Thornton 1997). In this study, the worksheet provided the impetus to focus on the problem-solving strategy the students were struggling with, using the drawing of free-body diagrams and a lecture demonstration with a student volunteer (Berg and Brouwer 1991, Roberts *et al* 2008, Sujarittham *et al* 2016). In particular, collaborative techniques were used abundantly. Hence, the 'intensity' of the active learning has been modified in a measured manner, incorporating different ways of incorporating active learning utilizing worksheets as a tool. Our study also shows that there is a saturation level, both from the point of view of how much can be fitted in and what the mean examination scores on the topic are. This possibly reflects the tension between scaffolding and time for making sense of the material.

## 5. Summary of results

This paper focuses on worksheets with a distinct subsection on note taking for facilitating active learning with the intent of shedding light on the intensity of active learning. Improvements were made to enhance student understanding and problem-solving skills on the topic of circular motion, a topic where students often face difficulties. The enhancements included using lecture demonstrations, increased use of free-body diagrams and a problem-solving strategy. Observations were made and physics education literature was used to inform the development. Pre-test, post-test and an examination question with simple scoring were used with large cohort sizes. The results show a trend for the mean scores to increase as the intensity of the active learning facilitated by worksheets increased. From years 2 to 5, the intensity had increased, but the mean examination scores were not statistically significantly different, suggesting a saturation level.

Our in-depth investigation indicates that the study of intensity can be a fruitful path to follow for researchers to examine how and which changes in intensity lead to better learning outcomes. For practitioners, it suggests that explicitly engaging students with problem-solving strategies may be a worthwhile endeavor. We suggest that the practitioner makes it clear that problem-solving requires a 'strategy'. Searching for an equation is a strategy, but it is not as useful as other strategies. However, just saying this once is not enough. The critical aspect is lecturers integrating the problem-solving strategy effectively into the teaching, taking time to introduce the problem-solving strategy as well as diligently and consistently using it themselves. Furthermore, they need to give students time to practise using the strategy; supporting and rewarding the students in their use of the strategy. Once the students are used to the idea of a 'strategy', other strategies can be introduced. The learner needs to grow into the idea that 'strategies' are important and be open to 'strategizing'. Our study also indicates that gradual modifications can lead to increases in student performance, but these results may well saturate. Finally, we would take the liberty of speculating why there is saturation. Is it because of the ceiling effect, where there is not much room for further improvement? Is it because of the attention span because so much has been packed in that students do not really have sufficient time to focus before being moved on? Is it because there is a subset of the cohort for whom this approach does not work? From the authors' experiences, a possibility is the role the problem-solving strategy played in enabling more students to engage with homework problems in this lecture-based course. In year 1 and 2, few students were engaging with homework. The problem-solving strategy provided a pathway for more students to apply themselves to their homework problems in later years. However, only a certain number of students could be reached via the problem-solving strategy, resulting in saturation in later years. We note that these possibilities all need further research. It is likely that the presence of saturation may differ for different topics and contexts. It is important to find a balance that works for most students, most of the time. Studies such as this assist in scoping the balance.

This study has occurred in one institution and on one topic, affirming current findings on active learning as well as providing new insight. It also provides some ideas of how research-based approaches can be used in large lecture cohorts. Further studies on different topics and with different cohorts investigating the intensity of active learning approaches could offer more possibilities for improving teaching practice.

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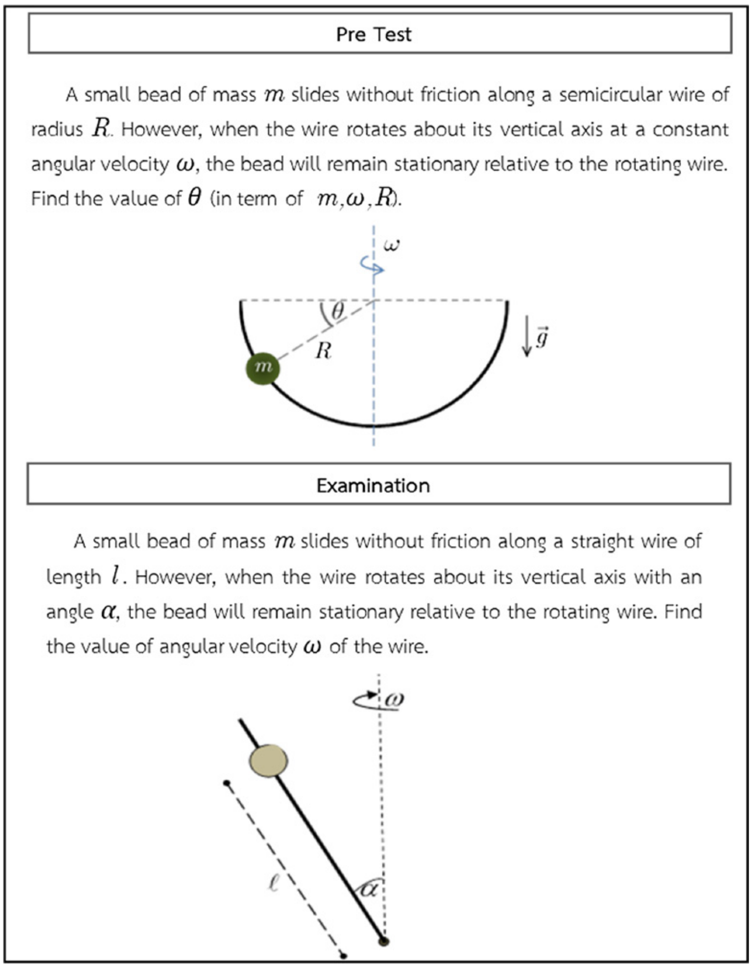
## Appendix A. The pre-test, post-test and the examination question; the same question was used for the pre-test and post-test (from Eambaipreuk *et al* 2015)



Pre Test

A small bead of mass $m$ slides without friction along a semicircular wire of radius $R$. However, when the wire rotates about its vertical axis at a constant angular velocity $\omega$, the bead will remain stationary relative to the rotating wire. Find the value of $\theta$ (in term of $m, \omega, R$).

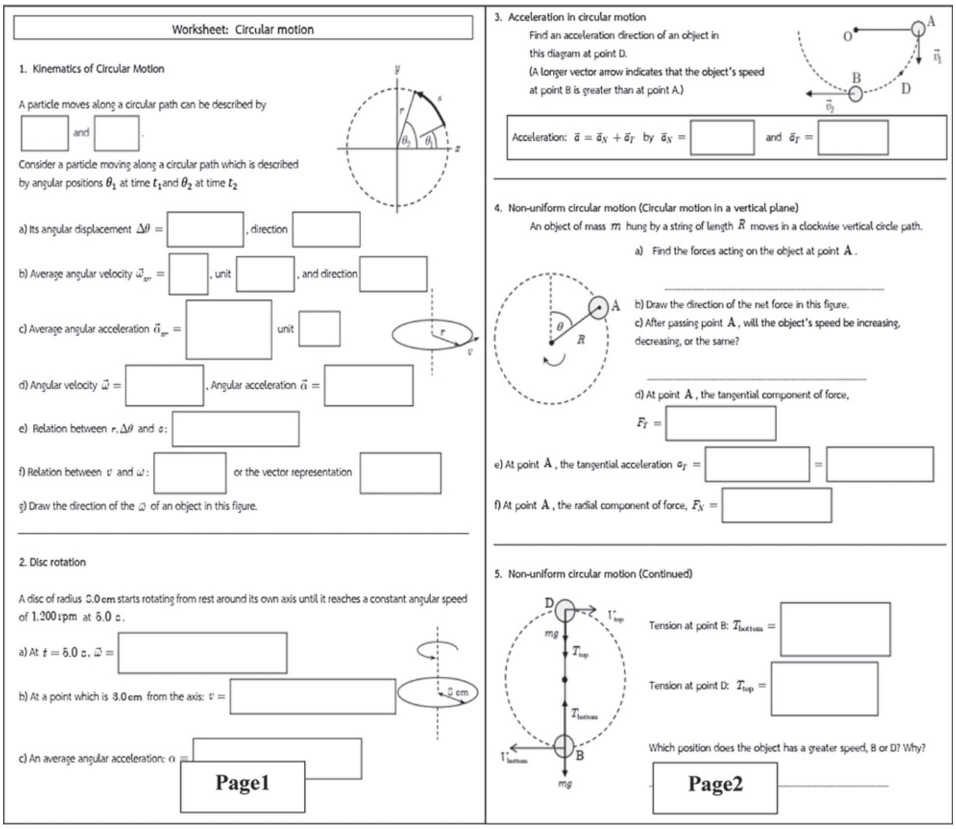


Examination

A small bead of mass $m$ slides without friction along a straight wire of length $l$. However, when the wire rotates about its vertical axis with an angle $\alpha$, the bead will remain stationary relative to the rotating wire. Find the value of angular velocity $\omega$ of the wire.

## Appendix B. The worksheets for year 1 and year 5 on circular motion used to facilitate active learning

Year1



Worksheet: Circular motion

1. Kinematics of Circular Motion

A particle moves along a circular path can be described by [ ] and [ ].

Consider a particle moving along a circular path which is described by angular positions $\theta_1$ at time $t_1$ and $\theta_2$ at time $t_2$

a) Its angular displacement $\Delta\theta =$ [ ], direction [ ]

b) Average angular velocity $\vec{\omega}_{av} =$ [ ], unit [ ], and direction [ ]

c) Average angular acceleration $\vec{\alpha}_{av} =$ [ ] unit [ ]

d) Angular velocity $\vec{\omega} =$ [ ], Angular acceleration $\vec{\alpha} =$ [ ]

e) Relation between $r, \Delta\theta$ and $s$: [ ]

f) Relation between $v$ and $\omega$: [ ] or the vector representation [ ]

g) Draw the direction of the $\vec{\omega}$ of an object in this figure.

2. Disc rotation

A disc of radius 8.0 cm starts rotating from rest around its own axis until it reaches a constant angular speed of 1,200 rpm at 5.0 s.

a) At $t = 5.0$ s, $\vec{\omega} =$ [ ]

b) At a point which is 8.0 cm from the axis: $v =$ [ ]

c) An average angular acceleration: $\alpha =$ [ ]

Page1

3. Acceleration in circular motion

Find an acceleration direction of an object in this diagram at point D.

(A longer vector arrow indicates that the object's speed at point B is greater than at point A.)

Acceleration: $\vec{a} = \vec{a}_N + \vec{a}_T$ by $\vec{a}_N =$ [ ] and $\vec{a}_T =$ [ ]

4. Non-uniform circular motion (Circular motion in a vertical plane)

An object of mass $m$ hung by a string of length $R$ moves in a clockwise vertical circle path.

a) Find the forces acting on the object at point A.

b) Draw the direction of the net force in this figure.

c) After passing point A, will the object's speed be increasing, decreasing, or the same?

d) At point A, the tangential component of force, $F_T =$ [ ]

e) At point A, the tangential acceleration $a_T =$ [ ] = [ ]

f) At point A, the radial component of force, $F_N =$ [ ]

5. Non-uniform circular motion (Continued)

Tension at point B: $T_{bottom} =$ [ ]

Tension at point D: $T_{top} =$ [ ]

Which position does the object has a greater speed, B or D? Why?

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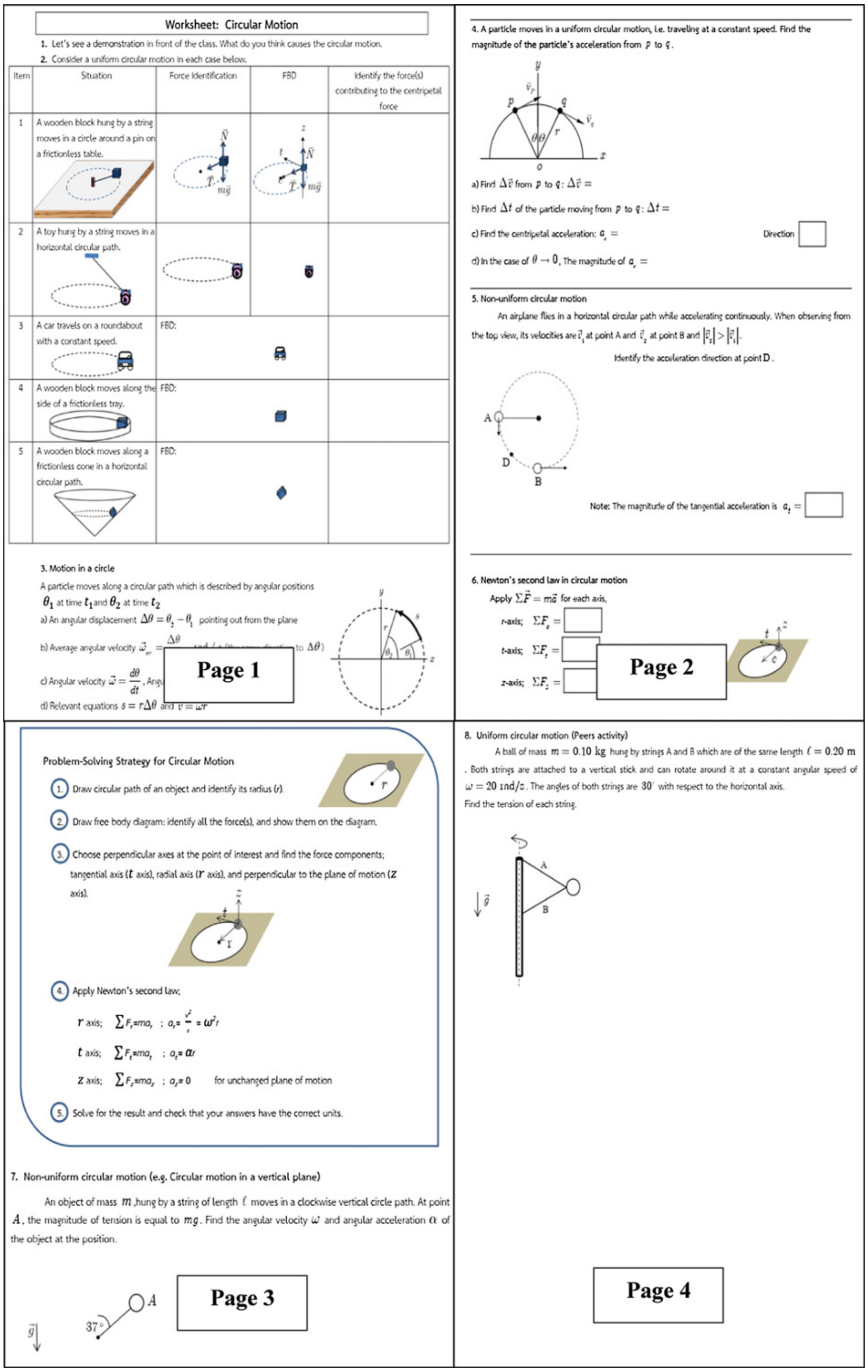
Year 5



Worksheet: Circular Motion

1. Let's see a demonstration in front of the class. What do you think causes the circular motion.
2. Consider a uniform circular motion in each case below.

| Item | Situation | Force Identification | FBD | Identify the force(s) contributing to the centripetal force |
|---|---|---|---|---|
| 1 | A wooden block hung by a string moves in a circle around a pin on a frictionless table. | $\vec{N}$, $\vec{T}$, $m\vec{g}$ | $z$, $t$, $\vec{N}$, $\vec{T}$, $m\vec{g}$ | |
| 2 | A toy hung by a string moves in a horizontal circular path. | | | |
| 3 | A car travels on a roundabout with a constant speed. | FBD: | | |
| 4 | A wooden block moves along the side of a frictionless tray. | FBD: | | |
| 5 | A wooden block moves along a frictionless cone in a horizontal circular path. | FBD: | | |

3. Motion in a circle

A particle moves along a circular path which is described by angular positions $\theta_1$ at time $t_1$ and $\theta_2$ at time $t_2$

a) An angular displacement $\Delta\theta = \theta_2 - \theta_1$ pointing out from the plane

b) Average angular velocity $\vec{\omega}_{av} = \frac{\Delta\theta}{\ldots}$ to $\Delta\theta$)

c) Angular velocity $\vec{\omega} = \frac{d\theta}{dt}$, Ang

d) Relevant equations $s = r\Delta\theta$ and $v = \omega r$

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4. A particle moves in a uniform circular motion, i.e. traveling at a constant speed. Find the magnitude of the particle's acceleration from $p$ to $q$.

a) Find $\Delta\vec{v}$ from $p$ to $q$: $\Delta\vec{v} =$

b) Find $\Delta t$ of the particle moving from $p$ to $q$: $\Delta t =$

c) Find the centripetal acceleration: $a_c =$ Direction

d) In the case of $\theta \to 0$, The magnitude of $a_c =$

5. Non-uniform circular motion

An airplane flies in a horizontal circular path while accelerating continuously. When observing from the top view, its velocities are $\vec{v}_1$ at point A and $\vec{v}_2$ at point B and $|\vec{v}_2| > |\vec{v}_1|$.

Identify the acceleration direction at point D.

Note: The magnitude of the tangential acceleration is $a_t =$

6. Newton's second law in circular motion

Apply $\Sigma\vec{F} = m\vec{a}$ for each axis,

r-axis; $\Sigma F_c =$

t-axis; $\Sigma F_t =$

z-axis; $\Sigma F_z =$

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Problem-Solving Strategy for Circular Motion

1. Draw circular path of an object and identify its radius ($r$).
2. Draw free body diagram: identify all the force(s), and show them on the diagram.
3. Choose perpendicular axes at the point of interest and find the force components; tangential axis ($t$ axis), radial axis ($r$ axis), and perpendicular to the plane of motion ($z$ axis).
4. Apply Newton's second law;

$r$ axis; $\sum F_r = ma_r$ ; $a_r = \frac{v^2}{r} = \omega^2 r$

$t$ axis; $\sum F_t = ma_t$ ; $a_t = \alpha r$

$z$ axis; $\sum F_z = ma_z$ ; $a_z = 0$ for unchanged plane of motion

5. Solve for the result and check that your answers have the correct units.

7. Non-uniform circular motion (e.g. Circular motion in a vertical plane)

An object of mass $m$, hung by a string of length $\ell$ moves in a clockwise vertical circle path. At point $A$, the magnitude of tension is equal to $mg$. Find the angular velocity $\omega$ and angular acceleration $\alpha$ of the object at the position.

**Page 3**

8. Uniform circular motion (Peers activity)

A ball of mass $m = 0.10$ kg hung by strings A and B which are of the same length $\ell = 0.20$ m. Both strings are attached to a vertical stick and can rotate around it at a constant angular speed of $\omega = 20$ rad/s. The angles of both strings are $30^\circ$ with respect to the horizontal axis.

Find the tension of each string.

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## Appendix C. Descriptive statistics, Welch's ANOVA test of the mean pre-test and post-tests scores, ANOVA test for mean examination question score and post hoc multiple comparisons using Bonferroni correction

Descriptive statistics for pre-test, post-test and examination question.

| | Statistic | Mean | Std error of mean (SEM) | Std deviation (SD) |
|---|---|---|---|---|
| Year 1<br>n = 287 | Total 4 exam | 1.61 | 0.092 | 1.555 |
| Year 2<br>n = 273 | Total 4 pre | 0.40 | 0.059 | 0.963 |
| | Total 4 post | 0.80 | 0.069 | 1.137 |
| | Total 4 exam | 1.99 | 0.092 | 1.512 |
| Year 3<br>n = 287 | Total 4 pre | 0.35 | 0.049 | 0.816 |
| | Total 4 post | 1.20 | 0.083 | 1.394 |
| | Total 4 exam | 2.11 | 0.102 | 1.722 |
| Year 4<br>n = 270 | Total 4 pre | 0.16 | 0.033 | 0.546 |
| | Total 4 post | 0.93 | 0.077 | 1.248 |
| | Total 4 exam | 2.42 | 0.097 | 1.595 |
| Year 5<br>n = 288 | Total 4 pre | 0.33 | 0.046 | 0.789 |
| | Total 4 post | 1.30 | 0.085 | 1.439 |
| | Total 4 exam | 2.26 | 0.089 | 1.502 |

Welch's ANOVA for pre-test

| | Statistic[a] | df1 | df2 | Sig |
|---|---|---|---|---|
| Welch | 6.259 | 3 | 604.71 | 0.000 |

Welch's ANOVA for post-test

| | Statistic[a] | df1 | df2 | Sig |
|---|---|---|---|---|
| Welch | 7.748 | 3 | 616.49 | 0.000 |

ANOVA for examination question

| | | Sum of squares | df | Mean square | F | Sig |
|---|---|---|---|---|---|---|
| Total score (4) | Between groups | 113.95 | 4 | 28.49 | 11.94 | 0.000 |
| Within groups | 3352.87 | 1405 | 2.39 | | | |
| Total | 3466.83 | 1409 | | | | |

[a]Asymptotically F distributed

Multiple comparisons using Bonferroni correction—output from SPSS version 24.

The first column is the dependent variable, second and third columns are the years being compared, fourth column is the difference between the means indicating the direction of the difference, fifth column the standard error, sixth column the statistical significance with those marked in red indicating $p$ values $< 0.05$ and the last two columns are the lower and upper bounds of the 95% confidence interval.

| Multiple comparisons using Bonferroni corrections | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | 95% Confidence interval | |
| Dependent variable | Compared years | | Mean difference | Std error | Sig | Lower bound | Upper bound |
| Pre-test total score 4 | Year 2 | Year 3 | 0.048 | 0.068 | **1.000** | −0.13 | 0.23 |
| | | Year 4 | 0.230[a] | 0.069 | **0.006** | 0.05 | 0.41 |
| | | Year 5 | 0.056 | 0.068 | **1.000** | −0.12 | 0.24 |
| | Year 3 | Year 2 | −0.048 | 0.068 | **1.000** | −0.23 | 0.13 |
| | | Year 4 | 0.182[a] | 0.068 | **0.047** | 0.00 | 0.36 |
| | | Year 5 | 0.008 | 0.067 | **1.000** | −0.17 | 0.19 |
| | Year 4 | Year 2 | −0.230[a] | 0.069 | **0.006** | −0.41 | −0.05 |
| | | Year 3 | −0.182[a] | 0.068 | **0.047** | −0.36 | 0.00 |
| | | Year 5 | −0.174 | 0.068 | **0.066** | −0.35 | 0.01 |
| | Year 5 | Year 2 | −0.056 | 0.068 | **1.000** | −0.24 | 0.12 |
| | | Year 3 | −0.008 | 0.067 | **1.000** | −0.19 | 0.17 |
| | | Year 4 | 0.174 | 0.068 | **0.066** | −0.01 | 0.35 |
| Post-test total score 4 | Year 2 | Year 3 | −0.367[a] | 0.112 | **0.006** | −0.66 | −0.07 |
| | | Year 4 | −0.193 | 0.114 | **0.542** | −0.49 | 0.11 |
| | | Year 5 | −0.488[a] | 0.112 | **0.000** | −0.78 | −0.19 |
| | Year 3 | Year 2 | 0.367[a] | 0.112 | **0.006** | 0.07 | 0.66 |
| | | Year 4 | 0.174 | 0.112 | **0.719** | −0.12 | 0.47 |
| | | Year 5 | −0.121 | 0.110 | **1.000** | −0.41 | 0.17 |
| | Year 4 | Year 2 | 0.193 | 0.114 | **0.542** | −0.11 | 0.49 |
| | | Year 3 | −0.174 | 0.112 | **0.719** | −0.47 | 0.12 |
| | | Year 5 | −0.295 | 0.112 | **0.050** | −0.59 | 0.00 |
| | Year 5 | Year 2 | 0.488[a] | 0.112 | **0.000** | 0.19 | 0.78 |
| | | Year 3 | 0.121 | 0.110 | **1.000** | −0.17 | 0.41 |
| | | Year 4 | 0.295 | 0.112 | **0.050** | 0.00 | 0.59 |
| Exam total score 4 | Year 1 | Year 2 | −0.375[a] | 0.131 | **0.041** | −0.74 | −0.01 |
| | | Year 3 | −0.644[a] | 0.128 | **0.000** | −1.00 | −0.28 |
| | | Year 4 | −0.812[a] | 0.131 | **0.000** | −1.18 | −0.45 |
| | | Year 5 | −0.632[a] | 0.128 | **0.000** | −0.99 | −0.27 |
| | Year 2 | Year 1 | 0.375[a] | 0.131 | **0.041** | 0.01 | 0.74 |
| | | Year 3 | −0.269 | 0.131 | **0.398** | −0.64 | 0.10 |
| | | Year 4 | −0.437[a] | 0.133 | **0.010** | −0.81 | −0.06 |
| | | Year 5 | −0.257 | 0.131 | **0.500** | −0.62 | 0.11 |
| | Year 3 | Year 1 | 0.644[a] | 0.128 | **0.000** | 0.28 | 1.00 |
| | | Year 2 | 0.269 | 0.131 | **0.398** | −0.10 | 0.64 |
| | | Year 4 | −0.168 | 0.131 | **1.000** | −0.54 | 0.20 |
| | | Year 5 | 0.012 | 0.128 | **1.000** | −0.35 | 0.37 |
| | Year 4 | Year 1 | 0.812[a] | 0.131 | **0.000** | 0.45 | 1.18 |
| | | Year 2 | 0.437[a] | 0.133 | **0.010** | 0.06 | 0.81 |
| | | Year 3 | 0.168 | 0.131 | **1.000** | −0.20 | 0.54 |
| | | Year 5 | 0.180 | 0.131 | **1.000** | −0.19 | 0.55 |
| | Year 5 | Year 1 | 0.632[a] | 0.128 | **0.000** | 0.27 | 0.99 |
| | | Year 2 | 0.257 | 0.131 | **0.500** | −0.11 | 0.62 |
| | | Year 3 | −0.012 | 0.128 | **1.000** | −0.37 | 0.35 |
| | | Year 4 | −0.180 | 0.131 | **1.000** | −0.55 | 0.19 |

[a]The mean difference is significant at the 0.05 level

## ORCID iDs

A Eambaipreuk https://orcid.org/0000-0001-6555-9823

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