รายงานวิจัยฉบับสมบูรณ์

โครงการ : การวิเคราะห์รูปแบบความคิดวิชาฟิสิกส์ของนักเรียนชั้นมัธยมศึกษาตอนปลาย

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เดือน ปี ที่เสร็จโครงการ ธันวาคม 2553

สัญญาเลขที่ MRG5080433

รายงานวิจัยฉบับสมบูรณ์

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ดร. พรรัตน์ วัฒนกสิวิชช์	ภาควิชาฟิสิกส์และวัสดุศาสตร์ คณะวิทยาศาสตร์มหาวิทยาลัยเชียงใหม่
รศ. ดร. สุพล อนันตา	ภาควิชาฟิสิกส์และวัสดุศาสตร์ คณะวิทยาศาสตร์ มหาวิทยาลัยเชียงใหม่

สนับสนุนโดยสำนักงานคณะกรรมการการอุดมศึกษา
และสำนักงานกองทุนสนับสนุนการวิจัย

กิตติกรรมประกาศ

ผู้วิจัยใคร่ขอขอบพระคุณ สำนักงานคณะกรรมการการอุดมศึกษา(สกอ.) และสำนักงานกองทุนสนับสนุนการวิจัย (สกว.) ที่ได้ให้การสนับสนุนงานวิจัยทุนพัฒนาศักยภาพการทำงานวิจัยของอาจารย์รุ่นใหม่ ประจำปี พ.ศ. 2550 และขอขอบคุณรองศาสตราจารย์ ดร. สุพล อนันตา ที่ปรึกษาโครงการที่ได้ให้การสนับสนุนและคำแนะนำในทุกด้านเพื่อช่วยให้อาชีพนักวิจัยของผู้วิจัยเริ่มต้นได้ ขอขอบคุณภาควิชาฟิสิกส์และวัสดุศาสตร์ คณะวิทยาศาสตร์ มหาวิทยาลัยเชียงใหม่ ที่ช่วยอำนวยความสะดวกในการใช้เครื่องมือ อุปกรณ์ และ สถานที่ นอกจากนี้ผู้วิจัยขอขอบคุณคณาจารย์ในกลุ่ม PENThai ที่เอื้อเฟื้อแบบทดสอบความเข้าใจฟิสิกส์ที่ได้รับการแปลเป็นภาษาไทยเรียบร้อยแล้ว ขอขอบคุณผู้ร่วมงานทุกท่าน ที่มีส่วนช่วยเหลือผู้วิจัยให้ดำเนินงานโครงการนี้สำเร็จลุล่วงได้ดี

(อาจารย์ ดร. พรรัตน์ วัฒนกสิวิชช์)
หัวหน้าโครงการ

บทคัดย่อ

รหัสโครงการ: MRG5080433

ชื่อโครงการ : การวิเคราะห์รูปแบบความคิดวิชาฟิสิกส์ของนักเรียนชั้นมัธยมศึกษาตอนปลาย

ชื่อนักวิจัย : อาจารย์ ดร. พรรัตน์ วัฒนกสิวิชช์
ภาควิชาฟิสิกส์และวัสดุศาสตร์คณะวิทยาศาสตร์ มหาวิทยาลัยเชียงใหม่
รองศาสตราจารย์ ดร. สุพล อนันตา
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โครงการวิจัยมีวัตถุประสงค์ที่จะประเมินรูปแบบความเข้าใจของนักเรียนชั้นมัธยมศึกษาปีที่ 6 ในหัวข้อฟิสิกส์ที่หลากหลายโดยใช้เทคนิคการวิเคราะห์แบบใหม่ที่เรียกว่า “การวิเคราะห์รูปแบบความคิด” เทคนิคนี้มีพื้นฐานมาจากงานวิจัยเชิงคุณภาพเพื่อที่จะนำเสนอรูปแบบความเข้าใจของนักเรียนในเชิงคุณภาพจากข้อมูลเชิงปริมาณ ด้วยการวิเคราะห์รูปแบบความคิดเราสามารถได้ข้อมูลความรู้รูปแบบอื่นๆ ที่นักเรียนมีและโอกาสที่นักเรียนจะนำความรู้นั้นไปใช้ในบริบทต่างๆ การวิเคราะห์รูปแบบความคิดประกอบไปด้วยการคำนวณ 2 แบบ—ปัจจัยความหนาแน่นและการประมาณรูปแบบความคิด การศึกษานี้เน้นเฉพาะการใช้การคำนวณการประมาณรูปแบบความคิด การวิเคราะห์รูปแบบความคิดอย่างมีประสิทธิภาพมากที่สุดนั้นจำเป็นที่ข้อมูลที่จะต้องเก็บมาจากแบบทดสอบปรนัยที่มีการออกแบบมาอย่างดี เช่น แบบประเมินความเข้าใจเรื่องการเคลื่อนที่และแรง (FMCE) และ แบบทดสอบความเข้าใจวงจรไฟฟ้ากระแสตรง (DIRECT) เป็นต้น แบบทดสอบฉบับล่าสุดประกอบด้วยคำถามแบบปรนัยจำนวน 70 ข้อ และแบบทดสอบใช้เวลา 2 ชั่วโมงในการทำ มีนักเรียนชั้นมัธยมศึกษาปีที่ 6 จำนวน 2,000 คน ทำแบบทดสอบจากทั่วประเทศ เมทริกซ์ความหนาแน่นของรูปแบบความคิดถูกสร้าง จากนั้นสถานะของรูปแบบความคิดถูกศึกษาลักษณะโดยการวาดจุดของรูปแบบความคิดลงบนกราฟรูปแบบความคิด ทำให้เห็นว่านักเรียนส่วนใหญ่ยังมีสถานะของความเข้าใจที่ไม่ถูกต้องในหัวข้อฟิสิกส์ต่าง ๆ

คำหลัก: การวิเคราะห์รูปแบบความคิด, ความเข้าใจวิชาฟิสิกส์, และแบบทดสอบความเข้าใจ

Abstract

Project Code: MRG5080433

Project Title: Model Analysis of high school students' understanding of physics

Investigators: Dr. Pornrat Wattanakasiwich

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Project Period: July 2, 2007 to Dec 2, 2010

This project aims to assess Grade-12 model of understanding in various physics topics by employing a new analysis method, called "model analysis". This method was established from qualitative researches in order to qualitatively represent a framework of student understanding from quantitative data. With model analysis, we can obtain students' alternative knowledge and the probabilities for students to use such knowledge in a range of equivalent contexts. The model analysis consists of two algorithms—concentration factor and model estimation. This study was concentrated on using the model estimation algorithm. In order to use the model analysis efficiently, the data must be collected from a well-designed multiple-choice test such as the Force and Motion Conceptual Evaluation (FMCE), the Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT) etc. The final version of the test was consisted of 70 multiple-choice questions. The test took two hours to complete. There were 2,000 Grade-12 students taking the test from all regions in the country. The model density matrices were constructed. Then the model states were characterized by plotting a model point on a model plot, stating that most students were still in misconception states in most physics topics.

Keywords: Model analysis, Physics conceptual understanding, Conceptual evaluation test

Output **จากโครงการวิจัยที่ได้รับทุนจาก สกอ. และ สกว.**

บทความวิชาการที่ได้ตอบรับหรือเสนอเพื่อตีพิมพ์ในวารสารวิชาการนานาชาติ (International publications) ที่จัดอยู่ในฐานข้อมูล ISI หรือ Scopus จำนวน 4 เรื่อง โดยเป็นผู้วิจัยหลัก 2 เรื่อง และผู้ควบคุมการวิจัย 2 เรื่อง และมีงานวิจัยในระดับชาติจำนวน 1 เรื่อง คือ

ผลงานวิจัยที่ตีพิมพ์ในวารสารระดับนานาชาติ (แสดงในภาคผนวก)

1.1 **Wattanakasiwich, P.,** & Ananta, S., “Model analysis: A quantum approach to analyze student understanding”. *Chiang Mai Journal of Science*, 36(1): 24-32 (2009). **ไม่มี impact factor อยู่ใน ISI**

1.2 **Wattanakasiwich, P.**, & Ananta, S. (2010). Analyzing Multiple-Choice Questions by Model Analysis and Item Response Curves. In *Proceedings of International Conference on Physics Education 2009* (pp.245-248), AIP Conference Proceedings 1263; American Institute of Physics: Melvilled, N.Y. **ไม่มี impact factor อยู่ใน Scopus**

1.3 Chanpichai, N., & **Wattanakasiwich, P.** (2010). Teaching Physics with Basketball. In *Proceedings of International Conference on Physics Education 2009* (pp.212-218), AIP Conference Proceedings 1263; American Institute of Physics: Melvilled, N.Y. **ไม่มี impact factor อยู่ใน Scopus**

1.4 Taleab, P., & **Wattanakasiwich, P.** (2010). Development of Thermodynamic Conceptual Evaluation. In *Proceedings of International Conference on Physics Education 2009* (pp.183-186), AIP Conference Proceedings 1263; American Institute of Physics: Melvilled, N.Y. **ไม่มี impact factor อยู่ใน Scopus**

ผลงานวิจัยที่ตีพิมพ์ในวารสารระดับชาติ

1.5 **Wattanakasiwich, P.** (2008). Assessing student conceptual understanding of force and motion with model analysis. *Chiang Mai University Journal of Natural Science*, 7(2), 307-315. **ไม่มี impact factor**

การเชื่อมโยงทางวิชาการอื่น ๆทั้งในและต่างประเทศ

นอกจาก รศ.ดร. สุพล อนันตา ผู้เป็นนักวิจัย ที่ปรึกษา ยังมีความร่วมมือในประเทศกับกลุ่มฟิสิกส์ศึกษา หรือ กลุ่ม PENThai (Physics Education Network of Thailand) ของมหาวิทยาลัยมหิดล และห้องวิจัยฟิสิกส์ศึกษาของจุฬาลงกรณ์มหาวิทยาลัย สำหรับในต่างประเทศมีการติดต่อกับกลุ่ม The Sydney University Physics Education Research (SUPER) เพื่อนำผลจากการเครื่องมือประเมิน FMCE มาวิเคราะห์โดยใช้ Model Analysis ซึ่งผู้วิจัยจะได้เดินทางไปทำวิจัยระยะสั้นกับทางกลุ่ม SUPER เป็นเวลา 6 เดือน (1 ก.พ. 54 ถึง 30 ก.ค. 54) ด้วยทุน Endeavour Research Fellowships ของกระทรวงศึกษาธิการ ประเทศออสเตรเลีย

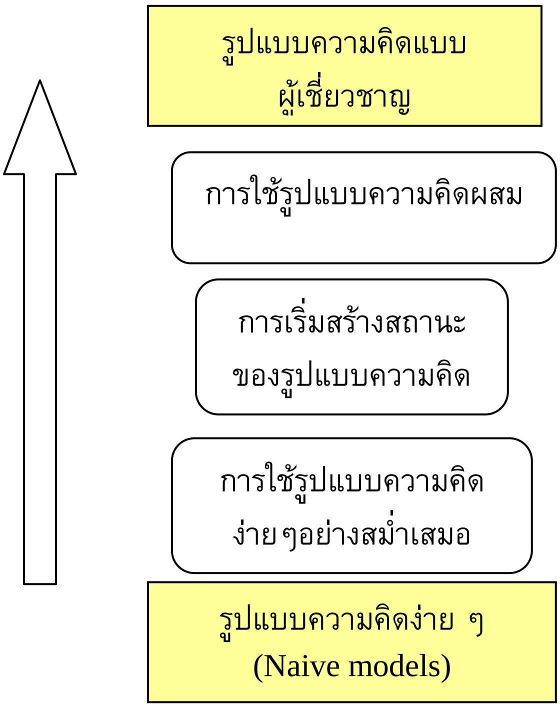
Executive Summary

1. ที่มาและความสำคัญของปัญหา

ฟิสิกส์เป็นหนึ่งในวิชารากฐานสำคัญสำหรับวิทยาศาสตร์และวิศวกรรมศาสตร์ ที่มีความสำคัญต่อเทคโนโลยีใหม่ๆ และจำเป็นต่อการแข่งขันในยุคเศรษฐกิจฐานความรู้ (Knowledge-based economy) แต่ว่ากลับมีผู้เรียนฟิสิกส์น้อยลงและขาดแคลนผู้ที่มีความรู้พื้นฐานทางด้านฟิสิกส์ รวมไปถึงการขาดแคลนครูสอนฟิสิกส์ นี่เป็นปัญหาที่วงการฟิสิกส์ทั่วโลกเผชิญ นักฟิสิกส์ในหลายประเทศได้เล็งเห็นถึงปัญหานี้และเริ่มให้ความสนใจกับการสอนฟิสิกส์โดยเริ่มทำการวิจัยทางด้านฟิสิกส์ศึกษา พบว่าปัญหาสำคัญของการเรียนฟิสิกส์คือผู้เรียนส่วนใหญ่มี *ความเข้าใจที่คลาดเคลื่อน (Misconceptions)* ก่อนที่จะเริ่มเรียนฟิสิกส์ ทำให้ผู้เรียนไม่สามารถเข้าใจหลักการของฟิสิกส์ที่ถูกต้อง(1) และมีผลต่อการเรียนต่อยอดความรู้ที่ต้องใช้ฟิสิกส์ต่อไป เพื่อแก้ปัญหานี้ทำให้การวิจัยด้านฟิสิกส์ศึกษากำลังเป็นที่สนใจอย่างมากในหลายประเทศโดยเฉพาะประเทศที่มีความก้าวหน้าทางด้านวิทยาศาสตร์และเทคโนโลยี แต่ในประเทศไทยยังขาดแคลนผู้ที่ทำการวิจัยทางด้านนี้ ดังนั้นการแก้ไขปัญหาการเรียนการสอนฟิสิกส์นี้จำเป็นต้องมีการเพิ่มศักยภาพการทำวิจัยทางด้านนี้ในประเทศไทย โดยเฉพาะงานวิจัยที่เน้นวิเคราะห์รูปแบบหรือลักษณะความเข้าใจที่ไม่ถูกต้องของผู้เรียน

การตรวจสอบว่าผู้เรียนมีความเข้าใจที่ไม่ถูกต้องหรือไม่ นักวิจัยทางด้านฟิสิกส์ศึกษาในสหรัฐอเมริกาและยุโรปได้ทำการวิจัยมากกว่า 30 ปี และได้สร้างเครื่องมือวัดความเข้าใจวิชาฟิสิกส์หลายหัวข้อด้วยกัน อย่างเช่น Force Concept Inventory (FCI) (2) หรือ Force and Motion Conceptual Evaluation (FMCE) (3) ใช้ในการวัดความเข้าใจเรื่องแรงและการเคลื่อนที่ โดยเครื่องมือเหล่านี้เป็นข้อสอบปรนัย มีการใช้เครื่องมือเหล่านี้อย่างแพร่หลายในการตรวจสอบความเข้าใจของผู้เรียนกลุ่มใหญ่ แต่การวิเคราะห์ข้อมูลที่ได้จากเครื่องมือยังไม่มีประสิทธิภาพ เพราะใช้การคำนวณหาเฉพาะอัตราส่วนร้อยละของคำตอบที่ถูกต้อง โดยไม่ได้นำคำตอบที่ไม่ถูกต้องมาวิเคราะห์ ซึ่งเป็นการสูญเสียข้อมูลที่จะบ่งบอกถึงลักษณะความเข้าใจที่ไม่ถูกต้องของผู้เรียน ดังนั้นใน ปี ค.ศ. 2006 Bao และ Redish(4) นักวิจัยทางด้านฟิสิกส์ศึกษาได้เก็บข้อมูลจากการใช้เครื่องมือ FCI และ FMCE ของนักศึกษาฟิสิกส์พื้นฐาน และนำเสนอการวิเคราะห์ข้อสอบปรนัยวิธีใหม่ที่สามารถบอกถึงรูปแบบความเข้าใจของผู้เรียนได้ เรียกว่า *การวิเคราะห์รูปแบบความคิด (Model Analysis)* เป็นเทคนิคการวิเคราะห์เชิงปริมาณที่สามารถให้ผลเป็นเชิงคุณภาพ โดยต้องอาศัยเครื่องมือวัดความเข้าใจที่ได้มาตรฐานโดยสร้าง*ตัวลวง (distractors)* จากผลการวิจัยเชิงคุณภาพเกี่ยวกับความเข้าใจที่ไม่ถูกต้องของผู้เรียน เพื่อที่จะทำให้ตีความผลการวิเคราะห์ออกมาเป็นรูปแบบความเข้าใจของผู้เรียนได้ การวิเคราะห์รูปแบบความคิดจะได้ผลดีมาก เมื่อใช้ในหัวข้อที่มีงานวิจัยสนับสนุนว่าผู้เรียนส่วนใหญ่มีรูปแบบความเข้าใจที่ไม่ถูกต้องที่โดดเด่นอยู่ โดย Bao และ Redish อธิบายว่าการ

วิเคราะห์รูปแบบความคิดนี้อาศัยแนวคิดว่าคนเรามีกระบวนการเปลี่ยนความคิด หรือพัฒนาการสถานะของความเข้าใจเป็นขั้นตอนดังภาพที่ 1 โดย*สถานะของรูปแบบความคิดผสม (Hybrid model state)* ซึ่งเป็นสถานะที่ผู้เรียนจะสามารถพัฒนาให้รูปแบบความคิดของเขาใกล้เคียงรูปแบบของผู้เชี่ยวชาญ (Expert model) ที่ถือว่าเป็นความเข้าใจที่เราผู้สอนต้องการให้ผู้เรียนมี



ภาพที่ 1: กระบวนการเปลี่ยนความคิด (Process of conceptual change)

จากภาพที่ 1 แสดงกระบวนการที่ทำให้เกิดการเปลี่ยนความคิด โดยเริ่มจากรูปแบบความคิดง่าย ๆ ที่ผู้เรียนมีมาก่อน ในที่นี้ร่วมถึงรูปแบบความคิดที่เป็นที่มาของความเข้าใจที่ไม่ถูกต้อง โดยการวิเคราะห์รูปแบบความคิดมีหลักการที่ว่าผู้เรียนที่กำลังเริ่มสร้างสถานะรูปแบบความคิดผสม จะสับสนในความคิดจึงให้คำตอบที่หลากหลาย โดยสามารถใช้หลักของความน่าจะเป็นมาช่วยในการวิเคราะห์ ถึงแม้ว่าเทคนิคการวิเคราะห์นี้จะยังใหม่ แต่มีศักยภาพสูงในการนำไปใช้ตรวจสอบความเข้าใจที่ไม่ถูกต้องในองค์ความรู้อื่น ๆ อย่างเช่น ทางด้านดาราศาสตร์ ด้านชีววิทยา และด้านเคมี เป็นต้น

เนื่องจากผู้วิจัยมีความถนัดและความสนใจที่จะตรวจสอบความเข้าใจของผู้เรียนทางด้านฟิสิกส์ เพราะพบว่าแม้กระทั่งนักศึกษาวิศวกรรมศาสตร์ส่วนใหญ่มีความเข้าใจที่ไม่ถูกต้องเกี่ยวกับแรงและการเคลื่อนที่ก่อนเรียน[5] ซึ่งทำให้ต้องการตรวจสอบรูปแบบความเข้าใจในหัวข้ออื่น ๆ ทางฟิสิกส์ เช่น พลังงานและโมเมนตัม ไฟฟ้า เป็นต้น และต้องการที่จะขยายงานวิจัยให้ครอบคลุมกลุ่มตัวอย่างก่อนที่จะเข้ามหาวิทยาลัย เพื่อใช้ผลการวิจัยนี้เป็นฐานความรู้สำคัญในการเสนอแนะการปรับปรุงการเรียนการสอนหรือหลักสูตรทั้งในระดับมัธยมศึกษาและในระดับอุดมศึกษา ประการ

สำคัญถือว่าเป็นงานวิจัยแรกที่นำการวิเคราะห์รูปแบบความคิดมาใช้กับความเข้าใจที่ไม่ถูกต้องในหัวข้อฟิสิกส์พื้นฐานอื่น ๆ ซึ่งสามารถนำไปต่อยอดงานวิจัยในการตรวจสอบความเข้าใจที่ไม่ถูกต้องในวิทยาศาสตร์สาขาอื่นได้ ดังนั้นงานวิจัยนี้มีวัตถุประสงค์ที่จะนำเทคนิคการวิเคราะห์รูปแบบความคิดมาตรวจสอบความเข้าใจในหัวข้อฟิสิกส์พื้นฐานของนักเรียนระดับมัธยมศึกษาตอนปลาย

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2. วัตถุประสงค์

2.1 เพื่อพัฒนาเครื่องมือวัดความเข้าใจฟิสิกส์พื้นฐานจากผลการวิจัยทางด้านฟิสิกส์ศึกษา

2.2 เพื่อตรวจสอบ*ความเที่ยงตรง (Validity)* และ*ความเชื่อมั่น (Reliability)* ของเครื่องมือ

2.3 เพื่อสำรวจรูปแบบความเข้าใจหัวข้อทางฟิสิกส์ของนักเรียนมัธยมศึกษาตอนปลายโดยใช้การวิเคราะห์รูปแบบความคิด (Model Analysis)

3. ระเบียบและวิธีวิจัย

3.1 ผู้เข้าร่วมการวิจัย (Participants)—เน้นไปที่นักเรียนระดับชั้นมัธยมศึกษาปีที่ 6 สายวิทยาศาสตร์

3.2 การเลือกกลุ่มตัวอย่าง—ใช้*การเลือกแบบเจาะจง(Purposive sampling)* โดยเก็บข้อมูลเฉพาะนักเรียนในห้องเรียนสายวิทยาศาสตร์ โดยไม่ให้เกิน 1% ของประชากรนักเรียนระดับชั้นมัธยมปีที่ 6 สายวิทยาศาสตร์ทั่วประเทศ หรือประมาณไม่เกิน 3,000 คน

3.3 ขั้นตอนการสร้างเครื่องมือประเมินความเข้าใจ

3.3.1 ค้นคว้าเอกสารและบทความทางวิชาการเพื่อสร้างเครื่องมือประเมิน

3.3.2 การตรวจสอบความเที่ยงตรง

- *ความเที่ยงตรงของเนื้อหา (Content validity)* โดยให้ผู้เชี่ยวชาญทางด้านฟิสิกส์วิเคราะห์
- ความเที่ยงตรงเชิงโครงสร้าง (Construct validity) หาจากการใช้*เทคนิคเชิงประจักษ์ชัด(Known Group Technique)*

3.3.3 การตรวจสอบความเชื่อมั่น

- ใช้ split-half และใช้สูตรของ Spearman-Brown prediction formula และใช้ Kuder-Richardson (KR_{20})

3.4 การเก็บข้อมูลจากเครื่องมือประเมินความเข้าใจฟิสิกส์พื้นฐาน

3.5 การวิเคราะห์รูปแบบความคิดและวาดกราฟรูปแบบความคิดของนักเรียนจากกลุ่มตัวอย่าง

3.6 สรุปรายงานผลและจัดทำรายงานฉบับสมบูรณ์

4. สรุปแผนการดำเนินการวิจัยตลอดโครงการในแต่ละช่วง 6 เดือน

ขั้นตอนของกิจกรรมวิจัย	เดือนที่										
	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-30	30-36	36-42
1. ออกแบบเครื่องมือฉบับแรกจากเอกสารและงานวิจัยที่เกี่ยวข้อง											
2. รายงานความก้าวหน้า		เดือน ที่ 6									
3. ตรวจสอบความเที่ยงตรงของเนื้อหา											
4. รายงานความก้าวหน้า				เดือ น 12							
5. ตรวจสอบความเที่ยงตรงเชิงโครงสร้าง											
6. ตรวจสอบความเชื่อมั่น											
7. เก็บข้อมูลตัวอย่าง											
8. รายงานความก้าวหน้า						เดือน ที่ 18					
9. กรอกข้อมูลกระดาษคำตอบ											
10. วิเคราะห์ข้อมูล											
11. แก้ไขแบบทดสอบให้ใช้เวลาน้อยลง											
12. เตรียมนำเสนอผลงานที่ประชุม สกว.									เดือน ที่ 27		
13. เก็บข้อมูลจริง											
14. วิเคราะห์ข้อมูล											
12. รายงานฉบับสมบูรณ์											

4. สรุปและวิจารณ์ผลการทดลอง และข้อเสนอแนะสำหรับงานวิจัยในอนาคต

จากการวิเคราะห์ทั้งแบบสถิติในรูปทั่วไป และการใช้การวิเคราะห์รูปแบบความคิดทำให้เราได้ข้อมูลความเข้าใจของนักเรียน พบว่าส่วนใหญ่ยังมีความเข้าใจที่ถูกต้องในเรื่องพลังงาน แต่ส่วนใหญ่ยังมีความเข้าใจที่ไม่ถูกต้องในเรื่องแรง โดยเฉพาะที่เกี่ยวข้องกับกฎของนิวตัน และนักเรียนมีความเข้าใจที่ไม่ถูกต้องเกี่ยวกับวงจรไฟฟ้ากระแสตรง พบว่านักเรียนชั้นมัธยมศึกษาปีที่ 6 ยังมีความเข้าใจที่ไม่ถูกต้องในเรื่องนี้อยู่เป็นจำนวนมาก ซึ่งผลนี้ทำให้แสดงว่าการสอนแบบที่ทำกันอยู่นั้นไม่ได้ช่วยให้นักเรียนตระหนักถึงความเข้าใจที่ไม่ถูกต้องของตนเอง หรือไม่ได้ช่วยให้นักเรียนเกิดการเรียนรู้ฟิสิกส์ที่ถูกต้อง

ข้อเสนอแนะสำหรับงานวิจัยในอนาคต

(I) การศึกษาวิจัยเพื่อปรับปรุงเทคนิคการวิเคราะห์รูปแบบความคิดให้สามารถวิเคราะห์ได้สะดวกขึ้น เนื่องจากปัจจุบันขั้นตอนการวิเคราะห์ค่อนข้างจะยุ่งยาก อาจจะมีการพัฒนา software หรือ Excel template เพื่อการวิเคราะห์โดยเฉพาะ

(II) การวิเคราะห์ยังทำในภาพรวม อาจจะนำข้อมูลมาแยกวิเคราะห์ตามภาค เช่น ภาคเหนือ ภาคอีสาน ภาคกลาง เป็นต้น เพื่อดูแนวโน้มของความเข้าใจของนักเรียนในแต่ละภาค ทั้งนี้อาจมีการวิเคราะห์เทียบกับลักษณะของโรงเรียนประกอบด้วย

(III) งานวิจัยในอนาคตที่มุ่งเน้นการเปรียบเทียบการวิเคราะห์รูปแบบความคิด กับการวิเคราะห์อื่นๆ ในทางสถิติ เช่น Factor analysis, Cluster analysis เพื่อดูความสามารถในการวิเคราะห์ของแต่ละเทคนิค

5. ภาคผนวก ประกอบไปด้วย

ภาคผนวก ก: Output จากโครงการวิจัยที่ได้รับทุนจาก สกอ. และ สกว.

ภาคผนวก ข: แบบทดสอบความเข้าใจฟิสิกส์ในหัวข้อ กลศาสตร์ เทอร์โมไดนามิกส์ และไฟฟ้ากระแสตรง

ภาคผนวก ก:

Output จากโครงการวิจัยที่ได้รับทุนจาก สกอ. และ สกว.

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Contributed Paper

Model Analysis: A Quantum Approach to Analyze Student Understanding

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Abstract

The objective of this study had two folds-1) investigating students' basic understanding of force and motion and 2) employing a new analysis method, called *model analysis*. This method helps obtain students' alternative knowledge and probabilities for students to use such knowledge in a range of equivalent contexts. The model analysis consists of two algorithms-*concentration factor* and *model estimation*. The data were student responses on Force and Motion Conceptual Evaluation (FMCE). 545 engineering freshmen taking an introductory physics with calculus at Chiang Mai University took both pre- and post-test. The concentration factor indicated that students had misconception in concepts of Newton's laws. Hence the class-model density matrices for both pre/post scores were constructed to determine characteristics of the pre/post class; eigenvalues and eigenvectors were calculated by the eigenvalue decomposition method. Results from model plots suggested that most students still had misconception about force-motion concept and had mixed model states about Newton's third law.

Keywords: model analysis, concentration factor, model estimation, FMCE, conceptual understanding, force and motion, Newton's laws.

1. Introduction

Learning is an extremely complicated process. However, researchers in many fields have investigated and developed models of students' learning process, in hope for improve learning and teaching. To understand the learning of physics, many physicists have done research to study student difficulties in learning physics. This kind of research has become a new field of physics research, called physics education research (PER). Over three decades, PER findings point out that most students come to a physics classroom with misconceptions, originating from their misinterpretations of everyday experience and previous instruction [1-4]. These misconceptions influence how students respond to instruction. To design effective teaching methods, physics instructors have to obtain student prior understandings.

The information of misconception obtained from PER findings has been used in creating attractive distractors for multiple choice test such as Force Concept Inventory (FCI) [4] and Force and Motion Conceptual Evaluation (FMCE) [6]. These tests are commonly used to probe student understanding in a large-scale setting, but only overall scores and average pre/post gains can be determined by classic analysis [7-9]. The model analysis was developed to extract information about models of student understanding from their responses to multiple-choice test [10-12]. In this case, models are defined as functional mental constructs that are associated with specific physics contexts and can be applied directly in different context instances to obtain explanatory results [3, 4]. Therefore, this study aims to investigate students' understanding of force and motion by using the model analysis.

2. MATERIALS AND METHODS

2.1 Data Collection

The data were collected by administering Thai-version of FMCE to students taking physics for engineering and agro-industrial students I (PHYS 207105). The FMCE, widely used to probe conceptual understanding of Newtonian mechanics, consists of 47 multiple-choice single response items and one open-ended question. Its items can be categorized into five clusters of basic mechanics concepts-velocity, acceleration, Newton's first and second laws, Newton's third law and energy. For each item of FMCE, if students consider that none of the choice is correct, they can answer choice J. In this study, the model analysis was used to analyse 545 complete responses of students who took both pre- and post-test.

2.2 Model Analysis

The model analysis consists of two algorithms-concentration factor and model estimation. The concentration factor shows a distribution of student responses, whether they are clustered on certain choices or scattered among all choices. The model estimation is a quantitative evaluation of student models of understandings derived from a numerical analysis of student responses on multiple-choice tests. This method is useful in analyzing student's knowledge states in large classes with well-designed multiple-choice questions.

2.2.1 The Concentration Factor

The concentration factor is for analysing the distribution of students' responses, which gives preliminary information about students' model of understanding. The distribution of responses can be determined from a concentration factor, *C*, having a value range between 0 and 1, where a higher value referring to more concentrated responses [10]. Consider *N* students response on a question having *m* choices. A single student response on this question can be represented by an *m* - dimensional vector $\vec{r}_k = (y_{k1},\ldots,y_{ki},\ldots,y_{km})$, where $k = 1,\ldots,N$ represents different students. Then all the student responses on one question are summed up to form the total response vector [10]:

$$\vec{r} = \sum_{k=1}^{N} \vec{r}_k = (n_1,\ldots,n_i,\ldots,n_m),$$

where n_i is the total number of student answering choice *i*. There are *N* students taking the test and every student provides answer, so. $\sum_i^m n_i = N$. The length of one students' response vector is [10]:

$$r_0 = \frac{\sqrt{\sum_i^m n_i^2}}{N},$$

where $\frac{1}{\sqrt{m}} \leq r_0 \leq 1$. Then the concentration factor, *C* can be calculated from [10]:

$$C = \frac{\sqrt{m}}{\sqrt{m}-1} \times \left(r_0 - \frac{1}{\sqrt{m}} \right)$$

This equation is derived under a condition that N has to be much larger than m or $N>>m$. This condition was satisfied in this case because the number of students or had a value of 545 and the number of choices in FMCE or was no more than 7 choices. To evidently display the distribution of student responses for each question, its combining score or S for the whole class is plotted against its concentration factor on an *S-C* plot, as shown in Figure 2.

2.2.2 Model Estimation

This algorithm of model analysis was a result of findings in fields of neuroscience, cognitive science, and education research. From neuroscience and cognitive science research, memory is found to be associative, and cognitive responses are productive and context dependent [4]. Hence given questions with different physical contexts, most students have difficulties in identifying an accurate physics concept. They tend to use pieces of knowledge that are induced by the surface features of the specific contexts [1-4, 10-12], so their answers are not consistent. They seem to function as if they hold a mixture of different models (a correct one and incorrect ones) without knowing the appropriate situation in which to apply them [10-12]. Bao and Redish [11] proposed that when students answer a particular physics question, the context of that question triggers them to activate or create a certain model, as shown in Figure 1. The process of model activation or creation is complicated, so only the probability of activating a certain model state could be obtained by analyzing students'

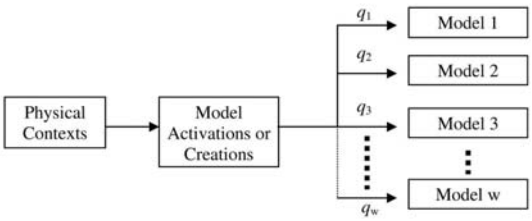

Figure 1. A diagram represents process of model triggers, where $q_1, q_2, ..., q_w$ represents probability of activating or creating a certain model [11].

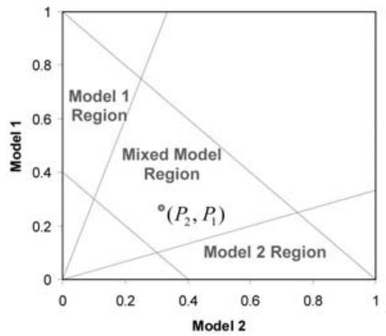

Figure 2. Model plot and meaning of some regions in the model plot [11].

responses to a well-designed instrument. Correspondingly, the process of model activation could be treated as a process of quantum measurement. The students' use of models in different contexts is defined as student model states [11], and model states can be represented with respect to a set of common models in a linear vector space, referred to as the model space. Similar to quantum system, each common model is associated with an element of an orthonormal basis, $\hat{e}_w$ called physical model vectors spanning the model space [10]. If there are w numbers of common models for a certain concept, these model vectors can be written mathematically as:

$$\hat{e}_1 = \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \end{pmatrix}, \quad \hat{e}_2 = \begin{pmatrix} 0 \\ 1 \\ \vdots \\ 0 \end{pmatrix}, \quad \ldots, \hat{e}_w = \begin{pmatrix} 0 \\ 0 \\ \vdots \\ 1 \end{pmatrix}$$

The student model state in a matrix form can be constructed by using student responses from a well-designed multiple-choice test such as FMCE or FCI. To construct a student model state of the k^{th} student as:

$$u_k = \frac{1}{\sqrt{m}} \begin{bmatrix} \sqrt{n_1^k} \\ \vdots \\ \sqrt{n_l^k} \\ \vdots \\ \sqrt{n_w^k} \end{bmatrix} = |u_k\rangle,$$

where n_l^k is numbers of the k^{th} student answers corresponding with Model I, w is total number of physical models in a concept group, and m is total number of questions in this concept group. Then Compute a student density matrix of k^{th} student (D_k) as follows:

$$D_k = u_k \otimes u_k^T = |u_k\rangle\langle u_k| = \frac{1}{m} \begin{bmatrix} n_1^k & \sqrt{n_1^k n_2^k} & \sqrt{n_1^k n_3^k} \\ \sqrt{n_2^k n_1^k} & n_{21}^k & \sqrt{n_2^k n_3^k} \\ \sqrt{n_3^k n_1^k} & \sqrt{n_3^k n_2^k} & n_3^k \end{bmatrix}$$

The class density matrix can be computed by summing up $\sum_{k=1}^{N} D_k$ and divided by number of students (N):

$$D = \frac{1}{N}\sum_{k=1}^{N} D_k = \frac{1}{N \cdot m} \begin{bmatrix} n_1^k & \sqrt{n_1^k n_2^k} & \sqrt{n_1^k n_3^k} \\ \sqrt{n_2^k n_1^k} & n_{21}^k & \sqrt{n_2^k n_3^k} \\ \sqrt{n_3^k n_1^k} & \sqrt{n_3^k n_2^k} & n_3^k \end{bmatrix}$$

Eigenvalues and eigenvectors can be obtained from the class density matrix by performing eigenvalue decomposition:

$$V^T D V = \begin{bmatrix} \sigma_1^2 & 0 & 0 \\ 0 & \sigma_2^2 & 0 \\ 0 & 0 & \sigma_3^2 \end{bmatrix},$$

where $\sigma_1, \sigma_2, \sigma_3$ are eigenvalues for the class density matrix. If the matrix has a large eigenvalue (> 0.65), then there are dominant features of the class model vectors, called a *primary vector* [12], which could be represented by the eigenvector of that dominated eigenvalue. Bao and Redish [11] proposed a model plot, a two-dimensional graph to represent the class use of two models. The primary vector $v_\mu = (v_{1\mu}, v_{2\mu}, v_{3\mu})^T$ with the eigenvalue σ_μ can be represented as a point on the model plot with a coordinate (P_1,P_2) [11], where $P_1 = \sigma_\mu^2 v_{1\mu}^2$ and $P_2 = \sigma_\mu^2 v_{2\mu}^2$. The class model point on the plot give information about the class model state. For example, if the model point is located in the middle, then most students in the class have a mixed model state about the concept.

3. RESULTS AND DISCUSSION

3.1 Concentration Factor

Figure 2 exhibited the S-C plot of pre- and post-test, where questions were sorted according to clusters of physics concept. Most questions in clusters of Newton's first and second laws (Force (1, 2)) and Newton's third laws (Force (3)) had low scores but high concentrations. This agrees with the results of Bao and Redish [10]. The low scores but high concentrations implied that there was the possibility of students having a multiple model of understanding or being in a mixed model state in these concepts [10]. Thus responses on these concepts were analysed in more detail by using the model estimation.

3.2 Model Estimation

3.2.1 Force-motion Concept

To use the model estimation, we needed models found from previous research to group incorrect responses. Through systematic physics education research, commonly recognized models of force and motion were identified as below [11], and a null model refers to other ideas or incomplete answers:

Model 1: It is necessary to have a force to maintain motion and there is no such thing as a "force in the direction of motion." (Correct)

Model 2: A force is needed to maintain motion. This model also includes the ideas that there is always a force in the direction of motion and that the force is directly related to the velocity of motion. (Incorrect)

Model 3: Null model

With the measurement data from FMCE, a single-student model state can be created. This state represents student probabilities in applying the different common models. Then the individual student model states are summed up over the class to create the class model density matrix. Using the eigenvalue decomposition, the eigenvalues and eigenvectors of the density matrix are obtained, and these give information about the state of the class's knowledge. The class model point is obtained and plotted on the model plot.

These models were used to identify distracters relating to each model. Then using pre- and post-test responses, each student model state was constructed. The class model density matrix was determined by adding all students' model states. Using the eigenvalue decomposition, the pre- and post-class eigenvalues and eigenvectors were calculated, as shown in Table 1. The model points were calculated using dominant eigenvalues and corresponding eigenvectors, and these points were plotted on the model plot (Figure 4). The post-class model point was located in the incorrect model (model 2) region. This

Table 1. The pre/post dominant eigenvalues, class eigenvectors and components of the class model point.

	Pre-	Post-
Dominant eigenvalues	0.82	0.79
Class eigenvectors	$\begin{bmatrix}-0.18\\-0.91\\-0.37\end{bmatrix}$	$\begin{bmatrix}-0.22\\-0.91\\-0.35\end{bmatrix}$
Model Point		
A vertical component	$P_1=(0.82)^2(-0.18)^2=0.02$	$P_1=(0.79)^2(-0.22)^2=0.03$
A horizontal component	$P_2=(0.82)^2(-0.91)^2=0.56$	$P_2=(0.79)^2(-0.91)^2=0.52$

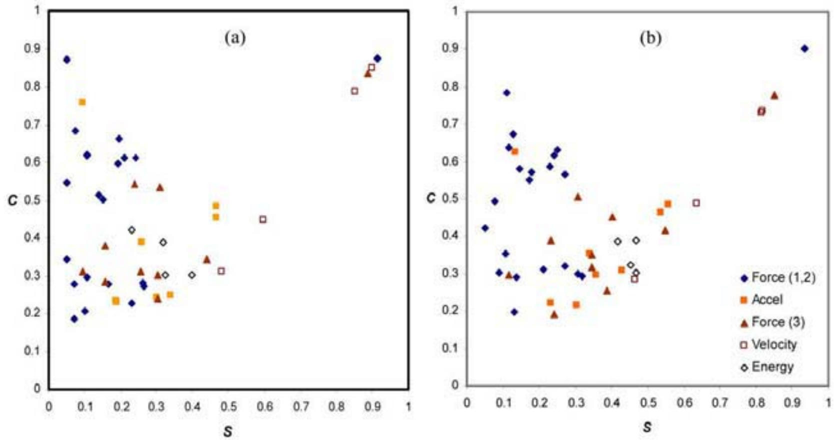

Figure 3. *S-C* plot of all questions categorized into five concept clusters - force (1,2), acceleration, force (3), velocity, and energy.

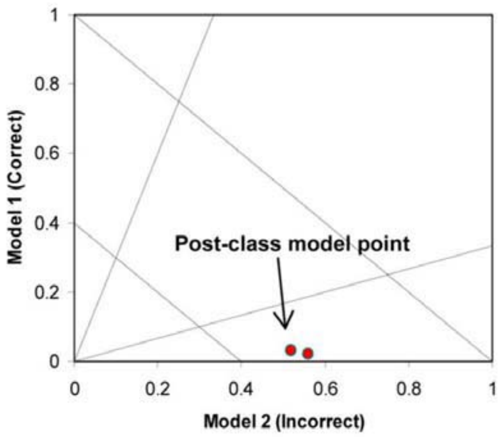

Figure 4. Model plot comparing between pre- and post-class model points about force-velocity concept.

indicated that most students in the class still had a misconception about force and motion even after an instruction. Since the characteristics of this misconception were known, so an instructor could use this information to improve teaching of the class. A small shift of post-class model point towards the correct model indicated a slightly better understanding of students in this class. Compared to Bao and Redish [11], our pre-class model point was located in the incorrect model, but their post-class model point moved to the correct model region ($P_2 = 0.21$, $P_1 = 0.46$). This may be due to different style of instruction; Bao and Redish [11] class were taught by using interactive teaching techniques.

3.2.2 Newton's Third Law

Maloney [13] found that students often used a *dominant principle* to reason about action-reaction force between two objects. Students often think that one object dominates over another because of a greater mass [13], a greater velocity, a greater acceleration [12],

Table 2. The pre/post dominant eigenvalues, class eigenvectors and model point components for the class density matrices of four misconceptions.

	Pre				Post			
	V	M	P	A	V	M	P	A
Dominant eigenvalues	0.91	0.92	0.92	0.91	0.88	0.89	0.91	0.89
Eigenvector	$\begin{bmatrix}-0.56\\-0.62\\-0.55\end{bmatrix}$	$\begin{bmatrix}-0.55\\-0.60\\-0.58\end{bmatrix}$	$\begin{bmatrix}-0.56\\-0.58\\-0.59\end{bmatrix}$	$\begin{bmatrix}-0.56\\-0.69\\-0.45\end{bmatrix}$	$\begin{bmatrix}-0.62\\-0.61\\-0.49\end{bmatrix}$	$\begin{bmatrix}-0.62\\-0.60\\-0.51\end{bmatrix}$	$\begin{bmatrix}-0.62\\-0.60\\-0.50\end{bmatrix}$	$\begin{bmatrix}-0.62\\-0.67\\-0.39\end{bmatrix}$
Model Point								
A vertical component	0.23	0.26	0.26	0.26	0.30	0.30	0.32	0.30
A horizontal component	0.32	0.31	0.28	0.39	0.29	0.29	0.30	0.36

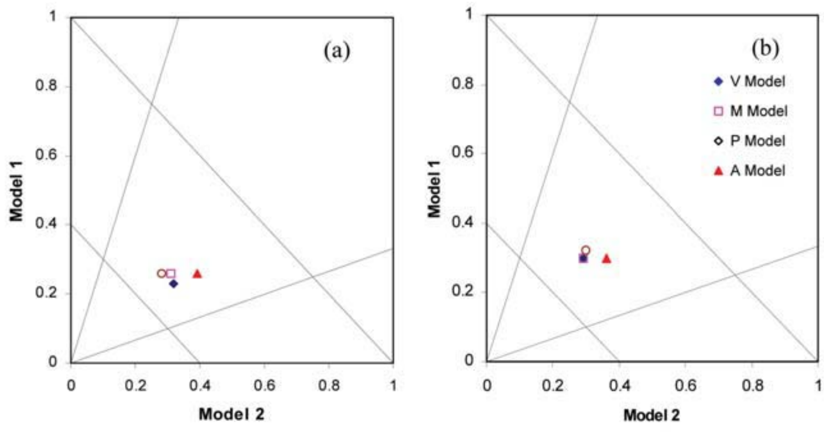

Figure 5. Model plot of Newton's third law concept.

or exerting a push [13]. These four misconceptions could be stated as follows:

V-model: Object with larger velocity exerts a larger force.

M-model: Object with larger mass exerts a larger force.

A-model: Object with larger acceleration exerts a larger force.

P-model: Object starting the push exerts a larger force.

These models were used to identify distracters on FMCE questions 30-39. Then we constructed the class model density matrix based on the model space spanning by a correct model, an incorrect model (V-model, M-model, A-model or P-model) and a null model. Therefore there were four class model density matrices, corresponding to each misconception. The dominant eigenvalues, eigenvectors and model points for each matrix showed in Table 2. The model plot of these matrices (Figure 5) pointed out that students were in mixed model states when answering Newton's third law questions. This agrees with Bao and Redish [10, 11]. This may be due to the context setting of the FMCE problems could have considerable influence on the activation of student's model.

4. Conclusion

In this investigation, the concentration factors indicated that our students had significant misconceptions about Newton's laws. This agrees with previous findings that most students had troubles understanding concepts of Newton's laws [1, 5-8, 10-13]. The data were analyzed by the model estimation to identify the class model state. The model plot of both pre- and post-class indicated a small improvement in conceptual understanding of the force-motion concept. For Newton's third law, both pre- and post-class were found to have a mixed model state. Different contexts of questions may trigger different model, so students used inconsistent model to answer questions. By using the model analysis, the major misconceptions was pointed out, so instructors could use this information to improve teaching and learning of the next class.

5. Acknowledgements

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Analyzing Multiple-Choice Questions by Model Analysis and Item Response Curves

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Abstract. In physics education research, the main goal is to improve physics teaching so that most students understand physics conceptually and be able to apply concepts in solving problems. Therefore many multiple-choice instruments were developed to probe students' conceptual understanding in various topics. Two techniques including model analysis and item response curves were used to analyze students' responses from Force and Motion Conceptual Evaluation (FMCE). For this study FMCE data from more than 1000 students at Chiang Mai University were collected over the past three years. With model analysis, we can obtain students' alternative knowledge and the probabilities for students to use such knowledge in a range of equivalent contexts. The model analysis consists of two algorithms—concentration factor and model estimation. This paper only presents results from using the model estimation algorithm to obtain a model plot. The plot helps to identify a class model state whether it is in the misconception region or not. Item response curve (IRC) derived from item response theory is a plot between percentages of students selecting a particular choice versus their total score. Pros and cons of both techniques are compared and discussed.

Keywords: Test analysis, multiple-choice test, model analysis, item response curves
PACS: 01.40.Fk

INTRODUCTION

Over the past 30 years, physics education research has been studied how students learn and understand physics in order to improve physics instruction. To probe students' conceptual understanding in a large-scale setting, multiple-choice test is the easiest to analyze and the cheapest to administer. Many physics education researchers have developed various multiple-choice conceptual tests to detect student misconceptions such as Force Concept Inventory (FCI) [1], Force and Motion Conceptual Evaluation [2], Conceptual Survey of Electricity and Magnetism (CSEM) [3] and Heat and Temperature Concept Evaluation (HCTE) [4]. Many studies employed these instruments to measure student understanding. However, the typical analysis of the multiple-choice tests not only fails to provide information about students' misconceptions but also ignores students' incorrect answers containing a large amount of valuable information [5,6]. Therefore in this study, we present two methods to analyze students' incorrect responses—model analysis [1] and item response curve (IRC) [3].

DATA COLLECTION

Participants were freshmen with engineering major taking an introductory physics I with calculus in 2006 and 2008 at Chiang Mai University. Thai-version of Force and Motion Conceptual Evaluation (FMCE) was used to probe student understanding of force and motion. FMCE was translated to Thai by physics education researchers from PenThai (Physics Education Network in Thailand) groups. Thai FMCE were used and validated in physics classes at both pre-college and first-year university levels. FMCE was administered to students on the first day of class as pre-test and the day after they finished learning topics of mechanics as post-test. Students were given an hour to finish the test and they received extra credit for compensation. Only responses from students taking both pre and post-test were used in data analysis. Figure 1 shows typical analysis of student responses including average scores and normalized gain, which can be calculated as in equation 1.

$$< g >= \frac{(\%post-test)-(\%pre-test)}{100-(\%per-test)} \qquad (1)$$

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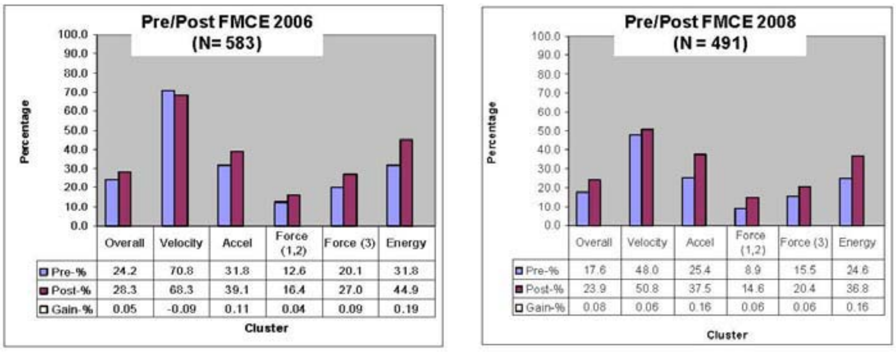

(a) (b)

FIGURE 1. Typical analysis of FMCE pre and post-test from [7] (a) 2006 academic year (b) 2008 academic year

MODEL ANALYSIS

With model analysis, we can obtain students' alternative knowledge and probabilities for students to use such knowledge in a range of equivalent contexts. The model analysis consists of two algorithms—concentration factor and model estimation [10]. This paper only presents results from using the model estimation.

An answer from each student is used to create a single-student model state, which represents student probabilities in applying the different common models. Then the individual student model states are summed up over the class to create the class model density matrix. The eigenvalues and eigenvectors of the density matrix are obtained, and these give information about the state of the class's knowledge.

The class model point is determined from eigenvector and plotted on the model plot. More detail of calculation can be found in [8-10]. The plot helps to identify conception level of a whole class, called a class model state whether it is in the misconception region or not, as shown in Fig 2.

This paper only presents results from using the model estimation algorithm to obtain a model plot for concepts of Newton's first and second law, which students from both classes got the lowest marks, as shown in Fig. 1. Through systematic physics education research, commonly recognized models of this conception were identified as below [10], and a null model refers to other ideas or incomplete answers:

Model 1: It is necessary to have a force to maintain motion and there is no such thing as a "force in the direction of motion." (Correct)

Model 2: A force is needed to maintain motion. This model also includes the ideas that there is always a force in the direction of motion and that the force is directly related to the velocity of motion. (Incorrect)

Model 3: Null model

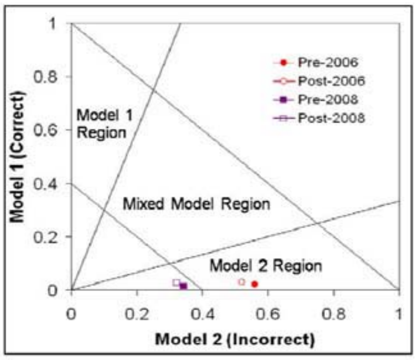

FIGURE 2. Model plot comparing between pre- and post-class model points and meaning of some regions in the model plot [10].

In the FMCE, four questions (questions 2, 5, 11 and 12) are associated with Newton's first and second law. Using the model estimation algorithm, model states for pre/post of 2006 and 2009 classes are presented in Fig. 3. Students in 2008 class entered a class with better understanding than 2006 class, but their class model state were still in the misconception region or Model 2 region. After physics instruction, model point of both 2006 and 2008 class shift slightly toward correct conception, as seen from Fig. 2. However, both classes understanding were still in the misconception region.

ITEM RESPONSES CURVES

Item response curve (IRC) derived from item response theory is a plot between percentages of students selecting a particular choice versus their total scores. IRC mainly is for evaluating quality of multiple-choice questions [11]. We use IRC to analyze class conceptual state of Newton's first and second laws in FMCE (excluding question 11). Then student responses for each question are plotted against total scores.

Figure 3 shows that Question 2 yields a step-function-like IRC [11]. This is a good question for discriminating students. Students with high conceptual understanding choose a correct answer and students with low understanding chose an incorrect answer. Also, this question helps an instructor to find out a misconception for students with low conceptual understanding. This misconception is not difficult to correct because not the whole class held this misconception.

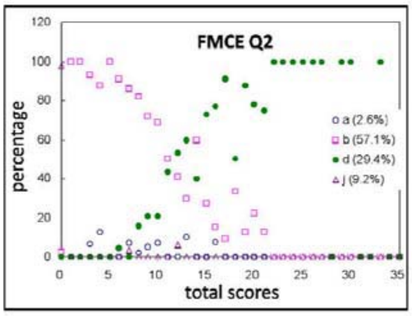

FIGURE 3. Item response curves for Question 2 from the FMCE (a correct answer choice is d).

Figure 4 shows evenly distributed responses from Question 5. Same numbers of students with high and low conceptual understanding chose incorrect answers. This result suggests that most students have misconceptions disregarding their ability levels. If we consider this result from a process of conceptual change [10], then this class conceptual understanding might be in a hybrid model state [8,10]. For students to reach a complete expert model, they need to go through a process of conceptual change [8-10]. The hybrid state is regarded as an important transitional stage for a student to reach a complete favorable conceptual change in learning physics. For instruction, we can use this question again in class and employ Peer Instruction approach to motivate students' process of conceptual change. This question is challenging enough for students at all levels of understanding.

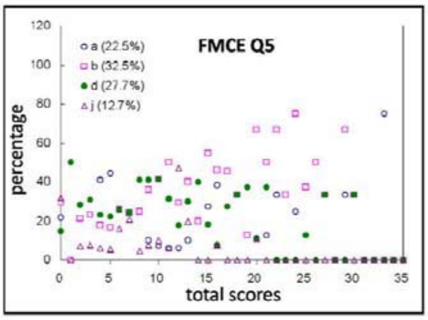

FIGURE 4. Item response curves for Question 5 from the FMCE (a correct answer choice is d).

Figure 5 shows the IRC analysis for Question 12, which has two dominated responses, choice *a* and choice *d*. This result suggests that the class has a major misconception. This question is good for identifying misconceptions that students have either before or after a physics instruction. To correct this misconception, an active teaching in physics such as Peer Instruction and Interactive Lecture Demonstration should be used in teaching this topic.

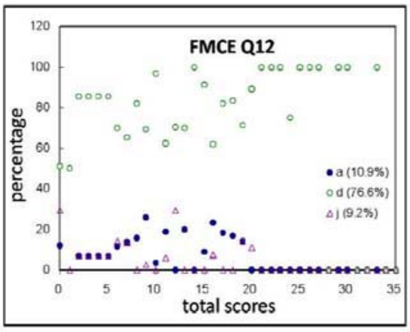

FIGURE 5. Item response curves for Question 12 from the FMCE (a correct answer choice is a).

CONCLUSION

Both analyses are good for identifying student misconceptions. Model analysis is good for determine overall misconceptions, but it is required a well-design questions to probe a certain misconception. IRC is excellent for identifying misconceptions in a specific context. IRC also is good for item analysis and for developing a diagnostic test. Different appearance of IRC can help a test developer categorize questions into:

(1) A question for discriminating students with different levels of understanding i.e. Question 2 from the FMCE.

(2) a question for identifying a hybrid model i.e. Question 5 from the FMCE.

(3) a question for spotting major misconceptions i.e. Question 12 from the FMCE.

However, IRC might be inconvenient to compare pre/post-test results from a diagnostic test.

ACKNOWLEDGMENTS

We would like to acknowledge Faculty of Science, Chiang Mai University, Thailand Research Fund (TRF) and the Commission on Higher Education (CHE) for financial support.

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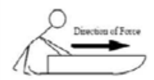
APPENDIX: SELECTED FMCE QUESTIONS

The selected questions including Question 2, 5, 11 and 12 from the Force and Motion Conceptual Evaluation[i] are shown here.

A sled on ice moves in the ways described in question 1-7 below. *Friction is so small that it can be ignored.* A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (A through G) which would keep the sled moving as described in each statement below.
You may use a choice more than once or not at all but choose only one answer for each blank. If you think that none is correct, answer choice **J**.



A. The force is toward the **right** and is **increasing** in strength (magnitude).
B. The force is toward the **right** and is of **constant** strength (magnitude).
C. The force is toward the **right** and is **decreasing** in strength (magnitude).

D. No applied force is needed

E. The force is toward the **left** and is **decreasing** in strength (magnitude).
F. The force is toward the **left** and is of **constant** strength (magnitude).
G. The force is toward the **left** and is **increasing** in strength (magnitude).

__2. Which force would keep the sled moving toward the right at a steady (constant) velocity?

__5. The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?

Question 11-13 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (**A** through **G**) to indicate the force acting on the coin for each of the case described below. Answer choice **J** if you think that none is correct. **Ignore any effects of air resistance.**

The force is **down** and constant.
The force is **down** and increasing.
The force is **down** and decreasing.
The force is zero.
The force is **up** and constant.
The force is **up** and increasing.
The force is **up** and decreasing.

___11. The coin is moving upward after it is released.
___12. The coin is at its highest point.

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Teaching Physics with Basketball

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Abstract. Recently, technologies and computer takes important roles in learning and teaching, including physics. Advance in technologies can help us better relating physics taught in the classroom to the real world. In this study, we developed a module on teaching a projectile motion through shooting a basketball. Students learned about physics of projectile motion, and then they took videos of their classmates shooting a basketball by using the high speed camera. Then they analyzed videos by using Tracker, a video analysis and modeling tool. While working with Tracker, students learned about the relationships between three kinematics graphs. Moreover, they learned about a real projectile motion (with an air resistance) through modeling tools. Students' abilities to interpret kinematics graphs were investigated before and after the instruction by using the Test of Understanding Graphs in Kinematics (TUG-K). The maximum normalized gain or <g> is 0.77, which indicated students' improvement in determining displacement from the velocity-time graph. The minimum <g> is 0.20, which indicated that most students still have difficulties interpreting the change in velocity from the acceleration-time graph. Results from evaluation questionnaires revealed that students also satisfied with the instructions that related physics contents to shooting basketball.

Keywords: kinematics graph, projectile motion, drags force, video analysis
PACS: 01.40.Fk

INTRODUCTION

Previous physics education researches about student expectations revealed that after physics instruction students perceived physics phenomena disconnected from their real-life experiences [1, 2]. Unless the materials is an examples that they see as relevant or directly related to student experience [2]. This is a serious problem in terms of students' attitudes in learning physics.

To motivate students and to help them relate physics to the real world, we developed a teaching module which integrates physics with other disciplines by using basketball as a theme. Also, we integrated video-analysis software in teaching kinematics graphs to help students better understand how to interpret and to relate three kinematics graphs.

PARTICIPANTS

Participants consisted of twenty-nine Grade-9 students at Chiang Mai University demonstration school. They enrolled in a science classroom project, supported by ministry of science and technology. The students learn science and mathematics from Chiang Mai University lecturers and learn other subjects from the demonstration-school teachers. The curriculum was particularly designed to promote scientific thinking skills through problem-based learning.

SPORT SCIENCE MODULE

In a sport science module, we integrated knowledge of physics, biology, physical education (PE) and statistics in order to teach about playing basketball. Total hours of teaching this module were 46 hours and the percentage of each subject hours is presented in Figure 1.

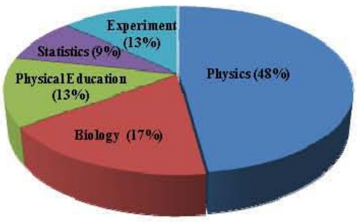

FIGURE 1. Hours distribution in the module

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In physics, we taught 1-D kinematics, projectile motion, Newton's laws, and a drag force. Also, students learned how to use a video analysis freeware, called Tracker [4]. In biology, students learned about functions of tendon, joint, bone and muscle when shooting a basketball. In physical education, students learned how to play basketball, especially shooting positions and how to measure strength of different muscle groups. For example, when throwing the basketball, the important muscle group is Triceps Brachii, located on the back of the upper arm [3]. The strength of this muscle group was measured by using a hand-grip dynamometer. In statistics, they learned how to calculate a correlation coefficient and to interpret correlation from a scatter plot. This module structure is shown in Figure 2. At the end of module, students designed, conducted an experiment to study a basketball and also wrote a report.

MODEL BASKETBALL MOTION

In "Motion analysis with Tracker" activity, students learned basic function of Tracker and a model builder function. Then they modelled a basketball motion with/without an air drag and compared with the real motion.

Making a Video

After learning basketball shooting position from physical education, students were asked to throw the basketball with a position similar to an overhand push shot, but they were instructed to fix their elbows and upper arms parallel to the ground and only moving their forearms to push the ball. To throw the ball, students' forearms had to be near the shoulder and launched the shot by a one-hand. Throughout the throw, both of their feet firmly planted on the ground and made both knees fixed with no bending.

The motion of each student was captured at 300 frames/second using a Casio EX-F1 camera. The camera was pointed at the right angles toward a plane of basketball motion, so the motion was recorded completely in two dimensions.

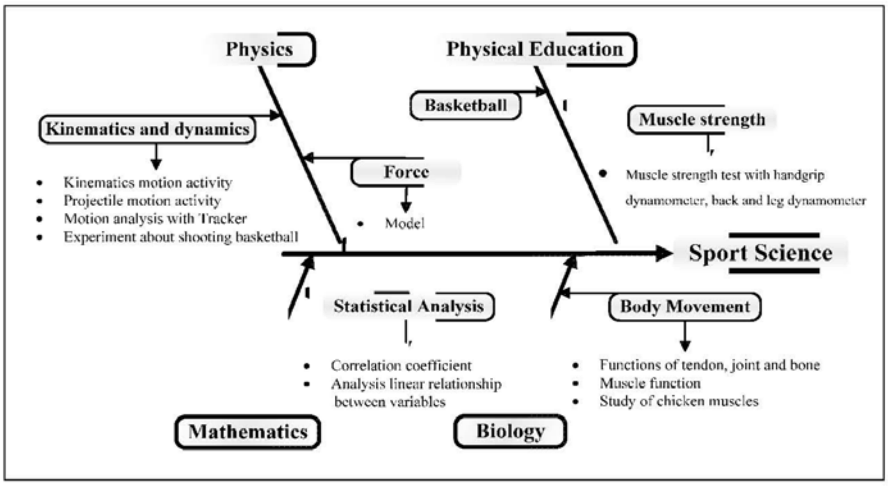


FIGURE 2. Structure of an integrated teaching module, called "sports science"

Video Analysis

Students first learned to use Tracker to analyze a projectile motion of a sample video. Then they were taught about force and Newton's laws. They also learned about air resistance, so they could model a real trajectory of a basketball. The models of basketball motion were used to compare with the real motion data. This step was determined by using the Model Builder function in Tracker. The first dynamics model accounted only a gravitational force or the basketball weight. The second model included the air drag force exerting on the basketball while moving through air.

The drag force depends on the basketball speed, air density and basketball size and shape. This can be written in term of an equation as:

$$F_D = \frac{1}{2} C_D \rho A v^2 \qquad (1)$$

where C_D is the drag coefficient (at acceleration 6.0-9.0 m/s^2, C_D = 0.5) [5], A is the cross-sectional area of the basketball (0.046 m^2), ρ is the air density (at 30 °C, ρ =1.164 kg/m^3) [6], and a mass of basketball is 0.6 kg. The drag force direction is tangent to the basketball path. Students were instructed to input a drag force due to the air resistance into the model builder and the simulated motion with drag was displayed, as shown in Figure 3.

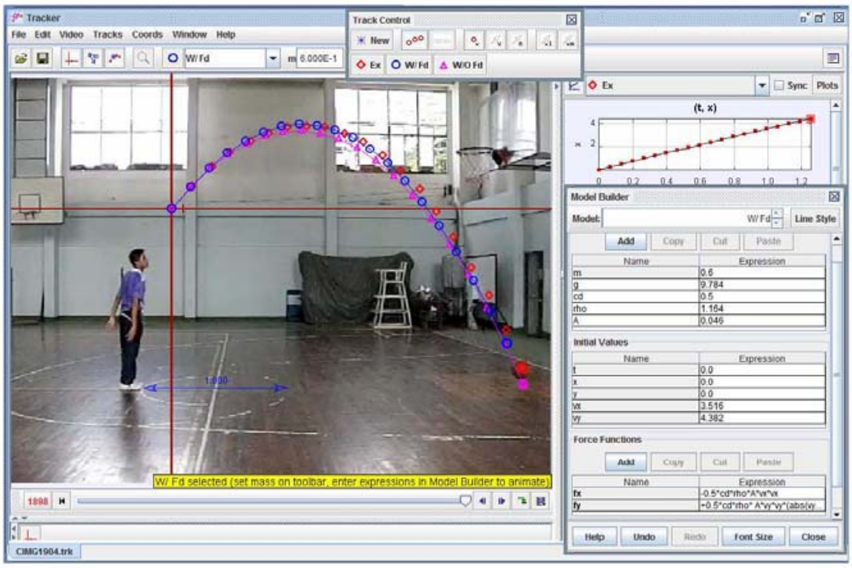


FIGURE 3. Modelling the actual basketball trajectory (◆), using a model without a drag force (△) and a model with a drag force (○) using Dynamics Particle Model function in Tracker

RESULTS AND DISCUSSION

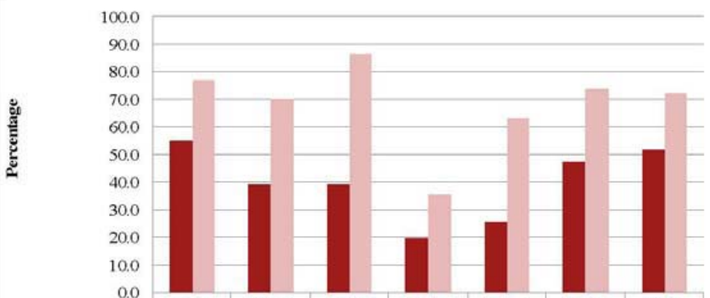
While working with Tracker, students learned about the relationships between three kinematics graphs through video analysis activity. Moreover, they learned about a real projectile motion (with an air resistance) through modeling tools. Students' abilities to interpret kinematics graphs were investigated before and after the instruction by using the Test of Understanding Graphs in Kinematics (TUG-K) [6]. The objectives of this test were presented in Table 1. Three items were written for each objective, so the test consists of 21 multiple-choice questions. Students' responses on both pre-test and post-test were used to determine a normalized gain [7], can be calculated as:

$$< g > = \frac{(\%post - test) - (\%pre - test)}{100 - (\%per - test)} \qquad (2)$$

From Figure 4, the maximum normalized gain or <g> is 0.77, which indicated students' improvement in determining displacement from the velocity-time graph. The minimum <g> is 0.20, which indicated that most students still have difficulties interpreting the change in velocity from the acceleration-time graph. This result is similar to previous findings [6]. Results from evaluation questionnaires revealed that students also satisfied with the instructions that related physics contents to shooting basketball.

TABLE 1. Objectives of the Test of Understanding Graphs Kinematics [6]

Objectives	Given	The student will
1	Position – Time Graph (x vs. t)	Determine Velocity
2	Velocity – Time Graph (v vs. t)	Determine Acceleration
3	Velocity – Time Graph (v vs. t)	Determine Displacement
4	Acceleration – Time Graph (a vs. t)	Determine Chang in Velocity
5	A Kinematics Graph	Select Corresponding Graph
6	A Kinematics Graph	Select Textual Description
7	Motion Description	Select Corresponding Graph



	Obj.1	Obj.2	Obj.3	Obj.4	Obj.5	Obj.6	Obj.7
%Pre-test	55.2	39.1	39.1	19.5	25.3	47.1	51.7
%Post-test	77	70.1	86.2	35.6	63.2	73.6	72.4

FIGURE 4. Percentage scores of pre-test, post-test and normalized gain from TUG-K.

CONCLUSION

In this module, we integrated physics with biology, physics education and statistics by using basketball as a theme. In physics part, we used a video analysis program to help students understand physics concepts better, especially kinematics graph. Using TUG, we found that students improve in their overall understanding of kinematics graph. This should be the result from using Tracker in analyzing the real motion and students did the activity of analyzing motion in terms of kinematics graph.

ACKNOWLEDGMENTS

This study has been supported by the Graduate School Chiang Mai University and department of physics and material science, faculty of science. Also, we would like to acknowledge Thailand Research Fund (TRF) and the Commission on Higher Education (CHE) for financial support.

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Development of Thermodynamic Conceptual Evaluation

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Abstract. This research aims to develop a test for assessing student understanding of fundamental principles in thermodynamics. Misconceptions found from previous physics education research were used to develop the test. Its topics include heat and temperature, the zeroth and the first law of thermodynamics, and the thermodynamics processes. The content validity was analyzed by three physics experts. Then the test was administered to freshmen, sophomores and juniors majored in physics in order to determine item difficulties and item discrimination of the test. A few items were eliminated from the test. Finally, the test will be administered to students taking Physics I course in order to evaluate the effectiveness of Interactive Lecture Demonstrations that will be used for the first time at Chiang Mai University.

Keywords: thermodynamics, conceptual understanding, physics education
PACS: 01.40.Fk

INTRODUCTION

For the past 30 years, numerous physics education research (PER) studies reveal that students enter physics classes with similar learning difficulties and preconceptions about how physical systems behave [1-4]. Most of these concepts are in conflict with accepted scientific one, so they are called misconceptions, alternative conceptions, naïve conceptions or "common sense". Many PER have investigated designed and constructed multiple-choice tests to probe these misconceptions both before and after an instruction. Physics instructors can use these results to design more effective teaching methods.

Our main objective is to develop an Interactive Lecture Demonstrations (ILDs) [2,4] in thermodynamics. To evaluate an effectiveness of ILD approach, students' knowledge before and after teaching had to be assessed, and compared with another class teaching with a traditional approach. Therefore, we have developed a test to evaluate student understanding of basic thermodynamic concepts, called Thermodynamic Conceptual Evaluation (TCE). The development and analysis of this test will be described in this article.

TEST DESIGN

The thermodynamic conceptual evaluation aims to evaluate students' understanding of concepts including work, heat, internal energy, the zeroth and the first law of thermodynamics and thermal processes. Most questions in this survey were obtained and adapted from previous PERs [5-8]. The first version of TCE consisted of 40 multiple-choice questions, and was reviewed by three physics faculty members at Chiang Mai University in terms of its content validity [9]. Five questions were eliminated and ten questions were modified based upon the feedback from three experts about their appropriateness and wording. The recent version of TCE consists of 35 multiple-choice questions covering three main conceptual areas in thermodynamics, as shown in Table 1.

ANALYSIS OF THE TCE

During the first semester of 2009, the TCE was administered to three groups of students. The first group consisted of 285 freshmen taking pre-test and 291 freshmen taking post-test. They were taking an introductory physics with algebra-based. The second group included 12 physics sophomores taking a thermal physics course and the third group consisted

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of 22 physics graduate students. Students were given an hour to finish the test. Test responses from the first group were used to calculate an item analysis. Also the overall quality of the test was measured by determining reliability and validity.

Item Analysis

The post-test responses of the first group were used to calculate item analysis—item difficulty and item discrimination. The difficulty for each item is displayed in Fig. 1, where 0.0 means no students answer correctly and 1.0 means all students answer correctly. Difficulty of items ranged from 0.1 to 0.9, which is a reasonable range.

Item discrimination was calculated by ranking the students according to total score and then selecting the top 27% and the lowest 27% in terms of total score. For each item, the percentage of students in the upper and lower groups answering correctly is calculated, and the difference of these percentages was a measure of item discrimination [1]. Figure 2 displays the discrimination index for each item. The index for each item ranges from -0.2 to a little over 0.6. The low discrimination index may due to that the item difficulty strongly related to the item discrimination [1]. To understand a possible cause of negative discrimination index, we investigated students' responses on item 13 and item 20. This result will be discussed on the next section.

TABLE 1. Categories of conceptual area

Conceptual Areas		Items
Temperature, Heat, and Zeroth Law of Thermodynamics		1, 2, 3, 4, 5, 6, 7
First Law and Process of Thermodynamics	- Isobaric process	8, 9, 10, 11, 12, 13, 14
	- Isochoric process	17
	- Isothermal process	15, 16
	- Adiabatic process	22, 23, 24, 25, 26, 27, 28
	- Cyclic process	19, 20, 21, 30, 31, 32
	- PV diagram	18, 29, 33, 34, 35

Quality Analysis

Generally to measure the overall quality of the test, reliability and validity are determined. We calculated a KR-20 coefficient, the most common method for measuring the internal consistency or the reliability [1,2]. The KR-20 coefficient equals to 0.60 while KR-20 $\geq$ 0.70 is considered to be reliable. However, this low value was due to that the TCE contains only 35 items. If we would like to increase the reliability, we have to increase more items on this test. Also this reliability value was appropriate for using this test as a tool to evaluate the ILD approach because a range of KR-20 from 0.5 to 0.6 is common for well-made classroom tests [1].

We measured two types of validity—content validity and construct validity. Three physics faculty members evaluated the content validity of TCE by rating each item on a five-point scale (1 being low and 5 being high) for reasonableness and appropriateness. Then the index of consistency was calculated based on five-rating scale. All items were received high score (> 4.0), so no items were either eliminated or modified.

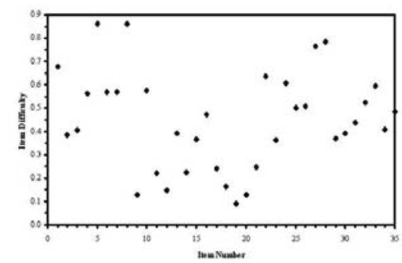


FIGURE 1. Item difficulty of each item on the TCE for 291 students.

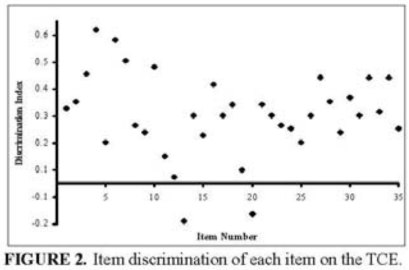


FIGURE 2. Item discrimination of each item on the TCE.

STUDENT RESULTS

The overall results of students in three groups are displayed in Table 2. The freshmen group took the TCE as a pretest and a posttest. They scored 43% on the pretest and 45% on the posttest. Additionally, data from sophomores majoring in physics were collected two weeks before finishing a thermal physics class. They scored 66%, which was highest among three groups. The last group was 12 graduate students at a Master level. They scored 52% on the TCE. The overall results from these three groups were compared on two main conceptual areas, as shown in Figure 3. The sophomores scored higher than the graduate students because they were learning thermodynamics at the time of test taking. Most graduate students had not taken any thermal physics course since they were undergraduate students.

To understand students' conceptions in thermodynamics, we analyzed each item in detail according to two main conceptual areas. We only used both pretest and posttest responses from the first group.

TABLE 2. Overall results for each student group.

Student Group	N	Mean Score (%)
Freshmen (Pre-test)	285	43
Freshmen (Post-test)	291	45
Sophomores	12	66
Graduate Students	22	52

Temperature, Heat and the Zeroth Law of Thermodynamics

Students seem to have an unclear conception of "boiling point." On item 2, students were given a statement about a boiling point as, "If I was camping on a high mountain, then I could not make a cup of tea because water does not boil at a high altitudes." Then they were given four different statements and asked to pick one statement that they mostly agreed on. 35% of students chose to agree with a statement, "The boiling point decreases when boiling at a high altitudes, but water still has a temperature of 100°C."

Ideal Gas Law

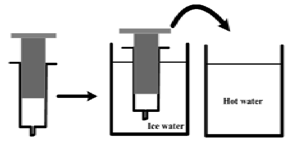
Most students seem to have difficulties with items about an ideal gas law, as displayed in Fig. 3. Item 9 and item 13, which relates to both an ideal gas law and an isobaric process, are items that students scored lowest. Item 9 is displayed on Fig. 4 (modified from [7]). 57% answered in the posttest that gas pressure would increase after the syringe was submerged under hot water. The correct answer is that the pressure remains the same because of the piston is in mechanical equilibrium at all time. Therefore the gas pressure from forces exerting from a piston weight and the atmospheric pressure are the same [8]. However, most students chose an incorrect answer and provided a brief reasoning that when the volume increases, the pressure also increases. From discussing with several students, they did not associate gas pressure with a piston weight at all. This result indicated that most students had a weak association of pressure and force. This resulted in students' confusion of an isobaric process. They recalled that the isobaric process has to have a constant pressure but they did not know what condition could be considered as having a constant pressure.

Use this information to answer questions 8-10.

A syringe with frictionless piston of mass M contains an ideal gas, as shown in figure below. Initially, it is submerged in ice-cold water. Finally, it is submerged into hot water, where it reaches a thermal equilibrium.

Please answers with these choices.

a) increases b) decreases c) remains the same



9. How does the final pressure of gas compared with the initial pressure? Please provide a brief reasoning.

FIGURE 4. Item 9 of the TCE

The First Law and Thermodynamic Processes

We obtained similar results as compared with previous physics education researches [5-6]. 53% of students answered incorrectly about work done in an isobaric process, having a volume expansion. Students confused about the sign of work done by gas. After briefly interviewing students, we found out that they were confused about a definition of work in physics with a definition in chemistry. In chemistry, they defined work as the work done on gas by the environment, so the sign of work are opposite.

From item 19, 20, 29, 30, 31 and 35, 30% of students chose an incorrect answer. This answer indicated that they considered work and heat depending on a thermodynamic state or being energy of a state, not energy transfer. Students seemed to confuse heat transfer in a closed system with heat transfer inside an isolated system.

Question 32 and 34 aimed to evaluate students' understanding of internal energy. We found that 30% of students chose an incorrect answer. This answer indicated that students considered the internal energy as transfer energy of a system, not energy of a state.

From item 14, 16, 17, 20, 31 and 35, students had difficulties applying the first law of thermodynamics to determine heat or internal energy in a different process. Further investigation such as an interview is required to gain insightful information about students' difficulties.

CONCLUSION

The TCE is a conceptual evaluation of students' basic knowledge in thermodynamics. The results obtained from this test are used in developing an interactive lecture demonstration on topics of heat transfer, thermodynamic process and heat engines [7]. To evaluate an effectiveness of these ILDs, the TCE will be administered to the classes teaching with ILD and compared with this class teaching traditionally.

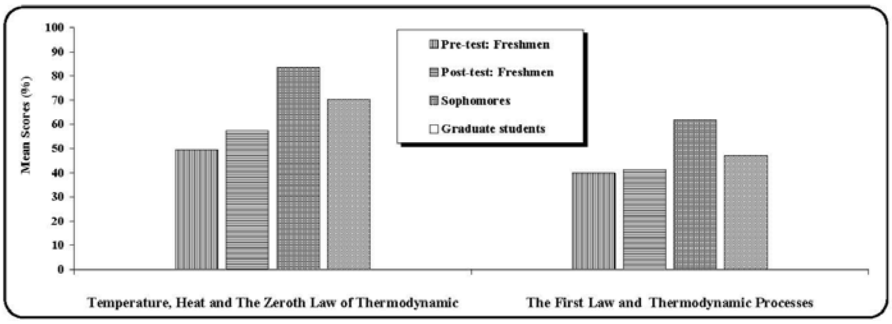


FIGURE 3. Mean score in each conceptual area for the different student groups.

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Assessing Student Conceptual Understanding of Force and Motion with Model Analysis

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ABSTRACT

This study aims to assess student conceptual model of understanding about force and motion by employing a new analysis method, called "model analysis". This method was established from qualitative researches in order to qualitatively represent a framework of student understanding. With model analysis, we can obtain students' alternative knowledge and the probabilities for students to use such knowledge in a range of equivalent contexts. The model analysis consists of two algorithms—concentration factor and model estimation. This paper only presents results from using the model estimation algorithm.

In order to use the model analysis efficiently, the data must be collected from a well-designed multiple-choice test. The Force and Motion Conceptual Evaluation (FMCE), the most well-known test for probing mechanics conceptual understanding was administered to 746 engineering freshmen taking an introductory physics with calculus at Chiang Mai University. Only 545 complete student responses were analyzed by the model analysis.

The class model density matrices for both pre/post scores were constructed. In order to determine characteristics of the pre/post class, eigenvalue decomposition was used to analyze both matrices. Each matrix had a large eigenvalue (> 0.65), indicating the dominant features of the single-student model vectors. This model eigenvectors well represented the overall model structure of pre/post class. Then the pre/post class model states were characterized by a class model point on a model plot. Both pre/post points were located in the incorrect model region, so both pre/post class states were still in a misconception state. However, there was a small shift of post-class model point towards the correct model, indicating a small improvement of overall understanding.

Key words: Model Analysis, FMCE, Conceptual Understanding, Force and Motion

INTRODUCTION

Over three decades, results from physics education research (PER) indicate that most students come to a physics classroom with misconceptions, originating from their misinterpretations of everyday's experience and previous instruction (McDermott and Redish, 1999). These misconceptions affect how students respond to instruction, so physics instructors should acquire student prior understandings in order to design more-effective teaching methods. In PER, free-response questions, interviews and multiple-choice questions are often used to probe student understandings.

In a large-scale setting, multiple-choice test is the easiest to analyze and the cheapest to conduct, but there is a lack of efficient methods to analyze student responses. Many physics education researchers have developed various multiple-choice conceptual tests to detect student misconceptions such as Force Concept Inventory (FCI) (Hestenes et al., 1992) and Force and Motion Conceptual Evaluation (FMCE) (Thornton and Sokoloff, 1998). Many studies employed these instruments to measure student understanding, however, the results from these instruments tend to be used to obtain overall scores and average pre/post gains (Hake, 1998; Huffman, 1998; Savinainen and Philip, 2002; Bonham et al., 2003).

The typical analysis of the multiple-choice tests not only fails to provide information about students' misconceptions but also ignores students' wrong answers containing a large amount of valuable information. Thus, the model analysis was developed to extract information about models of student understanding from their responses to multiple-choice test (Bao and Redish, 2006). This method is most effective in detecting well-defined misconceptions. These misconceptions were documented from qualitative researches that students often enter a classroom with a few number of strong naïve conceptions. These misconceptions are often in conflict with or encourage misinterpretations of the expert view. One of the well-defined misconceptions is about force and motion. Therefore, this study aims to investigate students' conceptions of force and motion by using the model analysis.

METHODOLOGY

Settings

The data were collected during the first semester of academic year 2006. The FMCE pre- and post-tests were given to students taking physics for engineering and agro-industrial students I (PHYS207105) on the first and the last day of class. Students were given 45 minutes to complete the FMCE. There were 746 students taking both pre- and post-test. After disregarding incomplete responses, only data from 545 students were analyzed by the model analysis.

Instrument

The FMCE was developed by Thornton and Sokoloff (1998). Since then it has become one of the most popular instruments used to probe student understanding of Newtonian mechanics. This test consists of 47 multiple-choice single-response items and one open-ended question. FMCE items can be categorized into five clusters of basic mechanics concepts—velocity, acceleration, Newton's first and second laws, Newton's third law and energy. For each item of FMCE, if students think that none of the choice is correct, they can choose to answer choice J. The Thai version of FMCE translated by Physics Education Network of Thailand (PENThai) was used to collect data.

TRADITIONAL ANALYSIS

The traditional and typical quantitative analysis of multiple-choice test was used in order to compare the results with the one using model analysis. Student responses were input into an excel template designed by Wittmann (2001), then the percentage of students' correct responses on pre-and post-test were plotted according to different clusters and overall scores, as shown in Figure 1. The percentage gain is calculated as follows:

$$\%\,Gain \;=\; \frac{\%\,post - \%\,pre}{(100 - \%\,pre)} \tag{1}$$

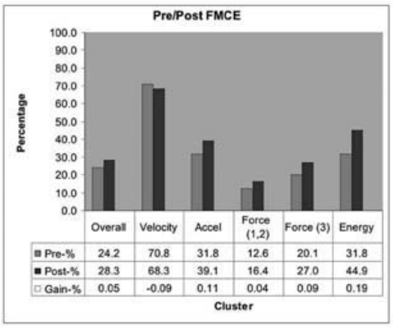

Figure 1: Percentage of Pre/Post FMCE scores categorized into overall and five concept clusters.

From Figure 1, Newton's 1st and 2nd laws cluster has the lowest percent correction in both pre/post test scores. Therefore, using the model analysis should provide useful results of student's understanding model in this topic.

MODEL ANALYSIS

The model analysis consists of two algorithms—concentration factor and model estimation. The concentration factor shows a distribution of student responses, whether they are clustered on certain choices or scattered among all choices. The model estimation is a quantitative evaluation of student models of understandings derived from a numerical analysis of student responses on multiple-choice tests. Since the concentration factor of student responses on FMCE has already been reported (Wattanakasiwich, 2006), this paper only presents the result from using the model estimation algorithm.

Theoretical Framework: Student Model State

It is a continuing effort among educational researchers to look for new ways to understand student learning process. However, learning is a complicated process, so it could not be measured directly. We can only model student ways of thinking and further improve our understanding of student learning. From physics teaching experiences, students are not consistent in solving problems and sometimes even use contradictory ideas to answer similar questions. In many cases when a similar concept is presented under different physical contexts, students may have difficulties in identifying the correct physics. They tend to use pieces of knowledge that are induced by the surface features of the specific contexts. Therefore, students seem to function as if they hold a mixture of different models (a correct one and incorrect ones) without knowing the appropriate situation in which to apply them.

From results of cognitive research, it may be of great interest to consider the student as always being in a consistent mental state. For students to reach a complete expert model, they need to go through a process of conceptual change, as shown in Figure 2. The mixed state is regarded as an important transitional stage for a student to reach a complete favorable conceptual change in learning physics. Hence, measurements of such mixed states have important values in assessment and instruction (Bao and Redish, 2006). Students in this mixed model state (sometimes referred to as a hybrid model) often combine certain parts of the new knowledge and parts of their existing knowledge. It is a solution of reconciliation to produce a locally-consistent model for two types of knowledge which are otherwise contradictory.

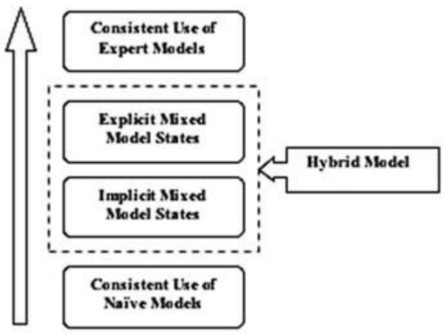

Figure 2: A process of model development leading to a conceptual change.

When students answer a particular physics question, the context of that question triggers them to apply a certain model. The process of model activation is complicated, so we cannot measure students' model states directly. Bao and Redish

(2006) proposed that the probability of activating model state could be obtained by analyzing students' responses to a well-designed instrument. In other words, the process of model activation could be treated as a process of quantum measurement. Accordingly, the mental state of the student can be represented with respect to a set of common models in a linear vector space, referred to as *the model space*. Each common model is associated with an element of an orthonormal basis, e_n as shown in Figure 3. This supports the fact that different mental models can have similar features. Bao and Redish (2006) indicated that studies in neuroscience about neural networks stimulated the ideas of using this representation.

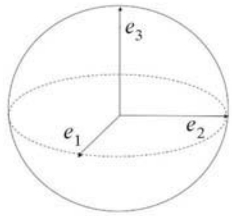

Figure 3: A model space consisting of three orthogonal model vectors—e_1, e_2 and e_3.

Construct Student Model State

In order to construct student model state, student responses from a well-designed multiple-choice test are required. The "well-designed" instrument has to be developed so that the choices of the question are designed to probe the different common student models. These models have been revealed from qualitative physics education research. There are 2 common models of force and motion found from PER and a null model refers to other ideas or incomplete answers:

Model 1: It is necessary to have a force to maintain motion and there is no such thing as a "force in the direction of motion." (Correct)

Model 2: A force is needed to maintain motion. This model also includes the ideas that there is always a force in the direction of motion and that the force is directly related to the velocity of motion. (Incorrect)

Model 3: Null model

In the FMCE, four questions (questions 2, 5, 11 and 12) are associated with Newton's first and second law. When analyzing each question, we can identify distracters associating with a particular model, as shown in Table 1.