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**Title:** Motivating Students to Learn STEM via Engaging Flight Simulation Activities.

# Motivating Students to Learn STEM via Engaging Flight Simulation Activities

## *Abstract*

Aviation is an interdisciplinary subject that has influenced human development over the last century. Learning about aviation exposes students to principles of flight, language, earth science, aeronautical engineering, flight training and airmanship. In K-12 education, educators have started to encourage children to learn science, technology, engineering and mathematics (STEM) subjects via aviation-themed activities to develop future scientists and engineers. This study investigated upper primary students' motivations to learn STEM via engaging in flight simulation experiences. The sample consisted of 345 10- to 13-year-old Hong Kong students from 8 primary schools. A modified version of the 31-item Science Motivation Questionnaire II (SMQ II) with four subscales with a focus on aviation was used. The relationships between intrinsic motivation, extrinsic motivation, self-efficacy and peer support across gender and performance were examined. The data obtained were analysed using factor analysis and a regression model. According to our model, students are most strongly motivated by peer support, followed by intrinsic motivation, and they are least motivated by self-efficacy. As expected, our results indicate that a gender gap exists in aviation-themed STEM learning. These findings can help educators to better understand students' perceptions of aviation science and further develop related learning activities.

**Keywords** Aviation, STEM education, Science motivation, Confirmatory factor analysis.

## Introduction

Aviation is a field of science and technology that plays a critical role in modern society and has significantly influenced global economic growth. In 2018, aviation accounted for US$2.7 trillion (3.6%) of the global gross domestic product (GDP), and it is expected to drive the world's economic growth to double in the next 20 years (ATAG, 2018). The International Civil Aviation Organisation has forecast that 7.8 billion passengers will travel by air in 2036 and has drawn attention to the shortage of skilled aviation professionals and pilots resulting from the high cost of pilot training and reduced interest in aviation careers (ICAO, 2017). The rapid global growth of demand for aviation during recent decades has made it necessary to rethink the content of the K-12 curriculum to motivate students to learn science, technology, engineering and mathematics (STEM) subjects via engaging aviation-themed activities. This will help to 'refuel' the aviation economy (Atkinson & Mayo, 2010).

Aviation has been viewed as an interdisciplinary subject that exposes K-12 students to principles of flight, language, earth science, aeronautical engineering, flight training and airmanship (Strickler, 1994; Kraus, 2014). One of the earliest studies in this area was designed by Pols, Rogers and Miaoulis (1994) to reinforce physics concepts relevant to aviation, such as pressure–area and pressure–velocity relations to demonstrate lift and drag in a hands-on wind tunnel design project for 8th grade students. The authors believed that science teachers should not only focus on developing students' science understanding but also on integrating technologies into the classroom. By using physical artefacts, teachers can make students ‘excited about what they are learning and maintain their interest throughout their lives’ (1994, p. 243).

Recent digital technologies enabling simulation and immersion have been shown to have great potential in helping student pilots experience conceivable scenarios and assist engineers with inspection and maintenance (Eschen et al., 2018; Lee, 2017). In K-12 education, teachers use technologies to consolidate students’ understanding of science concepts and develop their problem-solving skills (Guzey & Roehrig, 2009). In the US, the Federal Aviation Administration’s K-12 outreach programmes have involved students in simulating piloted and unmanned aircraft systems to explore aviation careers and enrich their STEM-related knowledge by solving aeronautical problems (Kraus, 2014). Better performance outcomes have been observed when digital applications are used to enhance student interaction and motivation (Dalgarno & Lee, 2010; Lee et al., 2016). For example, Rawat et al. (2018) used surveys to assess the use of flight simulators and other technologies related to aviation such as aircraft design, flow visualisation tunnels and 3D printers to support out-of-school laboratory experiments for students from 200 middle schools over 3 years. Approximately 75% of these students believed that the hands-on activities involving interactive equipment and rich digital media content facilitated the development of their STEM awareness and interest.

### *Hands-on science inquiry in aviation-themed activities*

During hands-on science inquiry, prior evidence-based studies demonstrated how students effectively gain knowledge from learning-by-doing aviation-themed activities, which involve the learning processes of asking questions, developing and using models, planning and carrying out investigations, interpreting data, using mathematical and science concepts, and constructing explanations from evidences. For example, English and King (2015) engaged 4th grade children in a paper plane design activity to trigger them to apply maths and science concepts (e.g., to change the plane’s direction, target a plane component and adjust its speed and forces) and engineering processes (e.g., problem scoping, idea generation, design and construction, evaluation and redesign). Texley (2007, p. 69) reported the use of FoilSim, an interactive simulation software package that determines the airflow around aerofoils of various shapes. This technology can foster middle school students’ hands-on inquiry in science and maths, allowing them to visualise the effects of jet engines on the speed and range of aircraft. Farr and Light (2019) designed a drone innovators programme using an integrated STEM approach (‘ask, brainstorm, plan, test and improve’) that enabled approximately 550 middle school students to benefit from deeper learning and career connections.

Digital technologies make it possible to apply the learning-by-doing approach, and to offer students authentic STEM learning experiences through gamification, visualisation and simulation (Aldrich, 2005, p. 79). This pedagogy is also recognised in aviation learning. Watters and Christensen (2014) developed school–industry partnerships to involve grade 8–12 students from 26 schools in applied learning about aspects of aerospace careers (e.g., human risk management and air traffic control), aeroskills (e.g., flight control, aircraft hardware and construction) and maintenance engineering (e.g., turbine engines, aerodynamic practices). Weiland and Mrusek (2020) designed a self-paced blended aviation course with live mentors for students aged 8–14, which significantly influenced the students’ interest in pursuing a career as a pilot or engineer in the air transportation industry.

### *Out-of-school STEM activities*

Out-of-school STEM learning in primary and middle schools has been the focus of numerous studies (e.g., Baran et al., 2016; NRC, 2015). In our developed aviation programme, STEM disciplines are integrated with hands-on flight simulation activities in an out-of-school setting, and can therefore contribute to the research field. The term ‘out-of-school’ refers to informal learning in unstructured learning environments outside classrooms and without the presence of a teacher (Gerber et al., 2001). Eshach (2007) further proposed that in addition to daily routines, occasional visits that include learner-led interactive activities can encourage out-of-school science learning. Students experience our aviation activities through visits to a university, where they can interact and play with the flight simulators under the guidance of aviation instructors. They can control the flight instruments to change the angle of the aeroplane’s wings and its position and apply the principles of flight in the tasks.

Out-of-school activities have been found to be extremely effective in developing students’ STEM motivation and achievement (Baran et al., 2016; Bollock & Belt, 2020). Baran et al. (2016) implemented a STEM education programme for 40 6th-grade students at a science centre to encourage them in STEM disciplines and careers. Out-of-school workshops can also help students make connections between academic knowledge and their daily lives through conducting experiments and investigations (e.g., designing wind turbines, using optical instruments and examining solar system models). In the field of aviation education, Bollock and Belt (2020) found that out-of-school aviation programmes at a summer camp effectively engaged and motivated 31 primary children in water-bottle rocket building, air traffic control-style communication and flight simulator sessions. In Hong Kong, frontline educators revealed through a government survey that they regarded out-of-school STEM activities as necessary, because they can help to strengthen students’ abilities to integrate cross-disciplinary knowledge and skills (EDB, 2015). Another study further reported that the out-of-school STEM ecosystem in Hong Kong was very active, and around 3,000 activities were successfully conducted in 2017 (e.g. competitions, exhibitions, external workshops, field trips), nearly triple the number recorded for 2016 (1,074) (Croucher Foundation, 2019). These out-of-school activities can effectively complement in-school programmes by involving specialists and external organisers, and thus providing human and equipment resources. Such informal hands-on learning opportunities can stimulate students’ interest in STEM academia and careers and encourage their critical thinking and creativity, and thus they gain a greater sense of accomplishment (Croucher Foundation, 2019).

### *Using a flight simulator as a stimulus*

Flight simulation is an innovative approach to teaching students about abstract science phenomena and engineering concepts in a technology-enhanced environment. For over 30 years, flight simulation has made major contributions to training in civil airlines and military organisations (Hays et al., 1992; Brown & Green, 2016; Lee, 2017). Flight simulators currently range from single-screen versions to virtual reality and research simulators with realistic cockpit layouts, extensive capabilities and high levels of realism, and are designed to help students learn about flight handling qualities and scientific and engineering concepts (Lee, 2017). They can be a motivational tool that allows students to determine and change key parameters (e.g., altitude, airspeed, vertical speed, heading) in various scenarios and thus interact fully within the simulator without associated costs and risks (Goodhew, 2010).

Flight simulation has increasingly been shown to foster collaborative activities in K-12 science and maths education in an active learning environment. For example, Aji and Khan (2018) used a quasi-experimental within-subject research design to investigate 25 7th–8th grade students’ use of flight simulators to learn physics and maths concepts. They found that a one-week STEM aviation camp was effective in increasing the self-efficacy of the students, improving their attitudes towards STEM, and enhancing their content knowledge. In a study of 45 middle school students and 10 teachers who took part in a 3-day aviation camp, the teachers suggested that using flight simulators as a pedagogical technique could increase the interest of high school students and enhance their maths and science learning (Khan et al., 2012). Ke and Carafano (2016) interviewed 20 middle school students in an earth science class and found that a high level of audio, visual and haptic sensory immersion in a flight simulation environment may foster learners' task engagement and procedural practice. Mathematics teachers also used a flight simulator to give students a new slant on linear equations in a middle school (Wood, 2013). DiLisi, McMillin and Virostek (2011) designed a STEM-focused youth aviation programme that used the aircraft simulator 'Wright Glider' and demonstrated the flight performance of various famous female aviators to around 350 grade K-5 children and 35 female high school students. They reported that this feminist and hands-on approach led to significant increases in the appreciation of STEM, the career interest of high school students and collaboration between students and educators.

Although extensive research into the potential of flight simulators has been conducted in K-12 and university settings, few studies have examined students' attitudes towards and motivations for learning STEM through aviation. This study addresses this research gap by examining the motivational patterns of student learning through aviation and by considering gender and flight performance ability. We investigate how students' intrinsic and extrinsic motivation, self-efficacy and peer support can be enhanced through engaging in flight simulation activities.

## Motivation to Learn STEM

The theoretical framework of this study begins with Bandura's (1986) social cognitive theory, with a particular focus on motivation and self-efficacy. Our research focuses on the motivational constructs in students' science learning. Motivation plays a significant role in students' learning and transferring problem-solving skills between subject disciplines (Bereby-Meyer & Kaplan, 2005) and in fostering the intent to pursue STEM disciplines and ultimately choose STEM careers (Wang & Degol, 2013). Motivated students tend to engage in academic behaviours such as asking questions, actively participating in lesson activities and collaborating with peers (Wentzel & Watkins, 2002).

In this study, we examined four constructs motivating the learning of aviation: intrinsic motivation to learn STEM for its own sake (Pintrich, 2004), extrinsic motivation to learn STEM as a means to an end, such as competition and reward (Ryan & Deci, 2000), self-efficacy motivation to ensure confidence that STEM learning can be achieved (Zeldin, Britner & Pajares, 2008) and peer learning motivation to interact and collaborate with other classmates (Bray et al., 2000). Amongst these motivational constructs, the relationships between intrinsic motivation, extrinsic motivation, self-efficacy, peer support across gender and performance were examined.

### *Relationships between motivational constructs*

Although few studies have measured the relationships amongst all of the four motivational constructs identified in our study, positive correlations between some of the constructs have been demonstrated for primary and high school students (e.g., Karadeniz et al., 2008; Shores & Shannon, 2010). Karadeniz et al. (2008) found a correlation between four constructs in the MSLQ in science and maths learning amongst primary and high school students in their psychometric study. Shores and Shannon (2010) found significant correlations between self-efficacy, intrinsic motivation and other motivational constructs that were able to predict the maths performance of 5th and 6th graders in the MSLQ. Lemos and Veríssimo (2014) examined the mathematics learning of 200 elementary school students and suggested that intrinsic and extrinsic motivation can coexist. They found that intrinsic motivation was consistently associated with better achievement, whilst a negative relationship between extrinsic motivation and achievement emerged. In terms of gender, most studies have focused on gender disparity in STEM learning rather than the correlations between motivational constructs. However, interest, motivation and learning outcomes in STEM fields at different ages have been examined in some studies (e.g., Hill, Corbett & St Rose, 2010; Chumbley, Haynes & Stofer, 2015; Cvencek et al., 2011; Shapiro & Williams, 2012), and a gender performance gap has been identified. Female students tend to have lower motivation and perform worse than male students in STEM fields (Hill, Corbett & St Rose, 2010) and may lose interest in STEM subjects due to a lack of peer support (Margolis, Fisher & Miller, 2000). In addition, only a few studies have focused on the correlations between intrinsic motivation, self-efficacy and other motivational constructs to predict learning achievement (e.g. Simon et al., 2015, Sartawi et al., 2012).

### *Intrinsic and extrinsic motivation*

Malone (1981, p. 335) asserted that 'challenge, fantasy, control, curiosity, cooperation, recognition and competition' are important to make learning interesting and engaging, thereby sustaining learners' continuous motivation (Habgood, Ainsworth & Benford, 2005). In self-determination theory, intrinsic motivation is defined as 'the doing of activity for its inherent satisfactions rather than for some separable consequences' (Deci & Ryan, 2000, p. 56). Intrinsic motivation gives individuals sufficient enjoyment to approach challenging tasks eagerly, persist in difficult situations and take pleasure in their achievement (Stipek, 1993). Strong correlations have been found between intrinsic motivation and academic achievement (Lepper, Corpus & Iyengar, 2005). In the present study, students engaged in a gamified flight simulation environment, which provided situational interest to increase their intrinsic motivation to learn science (Zoldosova & Prokop, 2006).

Extrinsic motivation is defined as motivation to avoid punishment or attain rewards from outside (Deci & Ryan, 2000). Extrinsically motivated students tend to perform to attain a desired grade and external rewards, such as awards and certificates. Studies have shown that students with higher intrinsic motivation typically persist in the face of academic challenges (Vallerand & Bissonette, 1992), are more engaged socially in learning (Walker, Greene & Mansell, 2006) and have higher innate curiosity about STEM learning (Honey & Kanter, 2013, p. 2).

### *Self-efficacy*

Bandura (1986) first defined self-efficacy as the possession of the capabilities necessary to perform a task successfully. If an individual believes that he or she does not have sufficient capability, they tend to have lower self-efficacy concerning a task. Wigfield, Eccles and Schiefele (1998) showed that students with higher self-efficacy are more likely to seek challenges and persist when they face challenges. Zeldin and Pajares (2000) found that students with high self-efficacy tend to discover cognitive strategies to mediate the challenges and thus improve their learning performance. Well-designed educational gamification, such as flight simulation, has great potential to enhance students' science content knowledge and self-efficacy, thus promoting their future STEM studies and careers (MacPhee, Farro & Canetto, 2013).

### *Peer support*

Collaboration in groups can make science learning meaningful (e.g., Chen, Wang & Lin, 2010; Hakkarainen, 2003; Zoldosova & Prokop, 2006). Research has shown that classroom interaction can stimulate students' motivation in classroom learning. An early study revealed that peer support and collaborative learning promotes helping behaviour in cooperative small groups to further improve students' performance and problem-solving (Webb, 1989). Since then, collaborative learning has been widely adopted to help students to master deeper science concepts through inquiry-based learning, thus improving students' learning achievements and motivations (Bray et al., 2000; Chiang et al., 2014). Crosnoe et al. (2008) found that grade 9–11 students' attitudes towards maths were associated with the achievement of their close friends and that this pattern was more consistent amongst girls than boys. Chen and Law (2015) revealed that collaborative learning had a positive effect on the science and technology learning performance of seventh-grade children, and this effect could be strengthened through connecting with the disciplinary knowledge embedded in digital tools, as this extends the potential of group collaboration. Studies of flight simulation activities have suggested that students with peer support are likely to perform better when using a space flight system than students who worked individually in a high school setting (Ke & Carafano, 2016). In addition, Chen et al. (2009) revealed that performing flight simulation tasks in groups would support team-level flying performance and decision-making processes, and enhance individual-level self-efficacy and performance amongst undergraduates. These research findings demonstrate the potential benefits of peer support in a flight simulation environment. (e.g., Chen & Law, 2015; Van Joolingen et al., 2005).

Although much of the research on aviation as a theme in STEM learning is still emerging, the handful of published empirical studies have been based on qualitative study, lesson observations, course evaluations and students' feedback. Although the potential of aviation learning has been highlighted by practitioners and researchers, quantitative evidence of how students perceive and are motivated by STEM learning in the context of aviation is scarce. Only 4 of the 25 studies conducted quantitative research to evaluate aviation learning programmes in terms of cognitive gains, career intention and interest. Most of the studies collected student feedback through case studies, lesson observations and focus group interviews. Appendix 1 presents a summary of their findings. The present study examines the motivational pattern across gender and performance ability amongst upper-primary children using engaging flight simulation technologies.

Based on the literature gap, we formulated two research questions:

RQ1. What is the correlational pattern between the four motivational constructs (intrinsic motivation, extrinsic motivation, self-efficacy and peer support), gender and learning performance when learning STEM via flight simulation activities in primary education?

RQ2. What are the predictors of students' task performance in a flight simulator based on these motivation constructs?

## Method

### *Participants*

The study sample consisted of 345 students from 8 primary schools in Hong Kong who enrolled in an out-of-school 1.5-hour flight simulation activity that included 3 scenarios: controlling, taking off and landing an aeroplane. Programme invitations were first sent to the eight schools. The selected students agreed to voluntarily complete the motivational questionnaire, and had not used a flight simulator before. Their participation also depended on their school's willingness to be involved in the study (Patton, 2002). The schools suggested that the programme should be one of their school activities, thus enriching students' STEM learning on a whole-class basis. The gender and grade distribution of the sample is shown in Table 1. The mean grade was 5.03 (SD = 0.822). Parental consent to complete the survey was obtained prior to the students' participation.

**Table 1** Demographic characteristics

| | *F* | % |
|---|---|---|
| **Gender** | | |
| **Male** | 167 | 47.2 |
| **Female** | 178 | 51.6 |
| **Grade** | | |
| **Primary 4** | 117 | 33.9 |
| **Primary 5** | 106 | 30.7 |
| **Primary 6** | 122 | 35.4 |

### *Measures*

We developed an aviation science motivation questionnaire (ASMQ) to measure the senior primary school students' motivation to learn about aviation. The questionnaire scales were adapted from the revised Chinese version of Motivated Strategies for Learning Questionnaire (MSLQ-RCV) (Lee, Yin & Zhang, 2010). As we aimed to examine the motivational pattern that influenced the students' STEM interest with a focus on aviation, the questionnaire was modified in the context of aviation and included statements pertaining to intrinsic motivation, extrinsic motivation, self-efficacy and peer support. The validity of the modified instrument was assessed using reliability and generalisability coefficients. This psychometric validation demonstrated adequate consistency amongst the motivational constructs in the MSLQ-RCV, and thus the results can be generalised to other contexts (Lee, Yin & Zhang, 2010). The students indicated their agreement with each statement on a 5-point Likert-type scale ranging from strongly agree to strongly disagree (see Appendix 2). In addition, the students were invited to complete an online questionnaire, which took around 15 minutes, at the end of the workshop after their 3 flight simulation tasks.

The wording of items was adapted to be context-specific; for example, 'I like what I am learning in school' was changed to 'I like what I am learning in the flying tasks'. After completing the climbing, taking off and landing tasks, students could track their flying performance in terms of safety concerns, stability and control issues, which were automatically assessed by the flight simulator X-Plane. The highest scores for each student were recorded and the differences between the perceived motivation of high and low performers were analysed.

Although the formula of the automatic scoring system is unknown, this low-cost software is sophisticated enough to be very close to real aircraft behaviour, in terms of systems, flight mechanics and performance, and can even be used for pilot training and system testing (Gu, Wu & Liu, 2009; Ribeiro & Oliveira, 2010; X-Plane, 2020). The X-Plane simulator had completed repeated validity tests with Cessna, and by successfully reproducing actual flights has enabled its aircraft design and performance to be assessed. Thus, it is a reliable tool for conducting related research (Wilson, Gutierrez & Nguyen, 2004). In addition, the flight simulator can support the teaching of maths and science concepts in classes via scenario-based flights (Khan et al., 2012; Dubick & Saunders, 2011). Students must have a knowledge of physics concepts to solve aeronautical problems, as otherwise they may simply guess; for example they may not know that pitching down the plane during a stall (i.e., a lift reduction in the aircraft) is the right action to gain sufficient forward airspeed and produce lift to balance the aircraft's weight.

### *Bringing the concepts of force and motion to life*

Children's conceptions regarding force and motion have been associated with their prior exposure in grades 4 to 6 in Science Education (HKEdCity, 2011; EDB, 2017) and can be developed through a series of reasoning within certain science domains, in a process known as science inquiry through modelling (White & Frederiksen, 1998; Bell et al., 2010). If 'force' remains an abstract concept, and students have not been made aware of it in other contexts, they may have difficulty understanding notions related to fluid mechanics, such as pressure difference, free-body diagrams, equilibrium analysis and the relationship between pressure and velocity. Typical misconceptions about force and motion relate to friction as a force, motion implying a force, confusion about position and velocity, action–reaction pairs acting on the same object, and velocity and acceleration (Bayraktar, 2007). Pine, Messer and John (2010) reported that teachers believed that their primary students had difficulties understanding forces because they could only view the effects of a force due to its invisible nature.

To shape students' learning style and thinking, science teachers use technology in their classes to help students visualise scientific phenomena to consolidate science concepts, and to develop students' problem-solving skills (Guzey & Roehrig, 2009). In the current study, three scenario-based tasks were given to students in an out-of-school informal setting. Such settings are commonly used to leverage students' interest in STEM education (EDB, 2015; Baran et al., 2016; Dabney et al., 2012). In each scenario, the instructor first introduced students to the basic maths and science concepts of free-body diagrams, air pressure, force and motion, spatial orientation, direction and bearings. A hands-on simulation activity then allowed the students to experience three flight scenarios and visualise these concepts. The overall best scores in the flight simulation tasks were recorded throughout in accordance with the assessment rubrics generated by the X-Plane software in a mobile device.

The flight simulation activities were age-appropriate for K-8 students, and we used the STEM resources designed by the National Aeronautics and Space Administration (NASA) and the General Aviation Manufacturers Association (GAMA) (NASA, 2020; Dubick & Saunders, 2011). We encouraged student engagement with these high-quality multimedia resources from world-renowned institutions, including videos and flight simulation demonstrations. Thus, we offered the students motivating, interactive and interesting learning experiences to help increase their understanding of physics (Altherr et al., 2003; Muller et al., 2008). In addition, five instructors from the Hong Kong Air Cadet Corps were invited to offer the students flight simulation workshops, and the role of our research team was to ensure that the teaching processes and resources used were consistent throughout the programme. The instructors encouraged students' hands-on science inquiry by asking questions, and the students were able to investigate the three flight scenarios and interpret the associated data through the flight simulator. Although the students often failed in the flight control trials, they were eager to explore the best approaches through trial and error, and attempted to improve their flying performance through providing explanations for their failures and generalising their successful experiences.

### *Three flying challenges via engaging in flight simulation activities*

In the flight simulation workshops, students were randomly assigned into groups of four, with each group consisting of various knowledge levels and mixed in terms of gender. Each team was divided into two pilots and two co-pilots. The positions were initially randomly assigned, and the teams rotated so everyone could take on multiple areas of responsibility. The students then practised in the groups to control the aircraft and follow the procedure checklists. The flight operations consisted of three sessions (i.e., controlling, taking off and landing). The students were encouraged to solve aeronautical problems together with their teammates, and through their awareness of the principles of flight they could manage these scenarios and address their control failures. Communication and collaboration amongst teams were essential, and the communication concerned various issues (e.g., advice, as the key to success, making observations and interpreting flight data). To successfully operate the flight simulator, all four teammates had to complete the tasks effectively and thus gain a ‘boarding pass’, which encouraged them to support each other in developing flight skills and knowledge. Students who failed several times heard a ‘disturbing engine noise’ from their devices.

In the first session, the students explored Bernoulli’s principle and Newton’s laws, which explain how aircraft fly and how to control them with flying instruments. First, the instructors asked the students, ‘How do aeroplanes fly?’ They showed videos demonstrating Bernoulli’s principle (e.g., the ping-pong ball air pressure experiment, putting your hand out of the window of a moving car) (ScienceWorld, 2020). Bernoulli’s principle explains how lift is generated under a streamlined aeroplane wing. When the air flowing past at the upper surface of the wing is moving faster than that at the bottom surface, the pressure on the top surface is lower than that on the surface below. The high-pressure air pushes up the wing, thus generating an upward lifting force. In addition to Bernoulli’s principle, the four forces of lift, weight, drag and thrust act on an aircraft in flight, and students could learn about these in a free body diagram in the first task (see Figure 1(e)). When the lift force is greater than the force of gravity, the aeroplane is able to fly, and when the thrust is greater than the drag force, it can move forward in flight (NASA, 2020).

Operating the flight instruments was the second learning objective. The instructors explained how to interpret the flight data, such as altitude, airspeed, vertical speed, heading, pitch and yaw movements, from the flight instruments in the three tasks (see Figure 1(a)). The instructors demonstrated take-off and landing, and the students could see that when the flaps were extended downwards, the wing area was raised and a greater lift force generated, even at a low airspeed. When the lift outweighed the gravitational force, the aeroplane took off. The flaps were extended again in landing to raise the drag force. The students were advised to keep the nose down when approaching the runway and lower the throttle, thus allowing the aircraft to fly more slowly without falling out of the sky (NASA, 2020; Dubick & Saunders, 2011). The students thus learned how aeroplanes make thrust for landing and understood the physics behind their flying decisions (e.g., changing direction with pitch, roll and yaw, use of flap, increase in power), thus ensuring a safe flight.

After the instructors gave 45-minute demonstrations, the students took on three flying challenges in the X-Plane flight simulator in the next session. The first task aimed to engage the students in controlling a Cessna’s pitch, roll and yaw from the pilot’s perspective by rotating their device horizontally and tilting it vertically. The instructors introduced students to spatial concepts on three principal axes (vertical, transverse and longitudinal). The students were then asked to adjust the power output to raise the plane’s airspeed. Thrust could be generated to make the plane fly further. The students could drag the screen to view the readings on their flight instrument panel in the cockpit, wing attachments and surroundings.

The second task required the students to produce extra lift for take-off. The students became aware of how the four forces act on the plane. The backs of the wings must be activated downwards from the trailing edge to increase the wing area and curvature of the aerofoil, thus generating a greater lift force even at a low airspeed. The lift force continues to rise as airspeed increases. At the moment when lift is greater than the gravitational force of the Cessna, it takes off. During landing, in the third task, the flaps and slats are extended downwards to generate drag, and the spoiler is activated to reduce lift. The students had to keep the Cessna’s nose pointing down the runway and lower the throttle. Then, they had to pull in more flaps to further slow the plane, allowing them to control the speed without falling out of the sky. Although some of the related concepts had not been formally taught in elementary science lessons, most of the participants revealed that they had experience of designing paper planes, water rockets and force-and-motion activities in their upper-primary STEM learning. Figure 1 illustrates the flight simulation tasks.

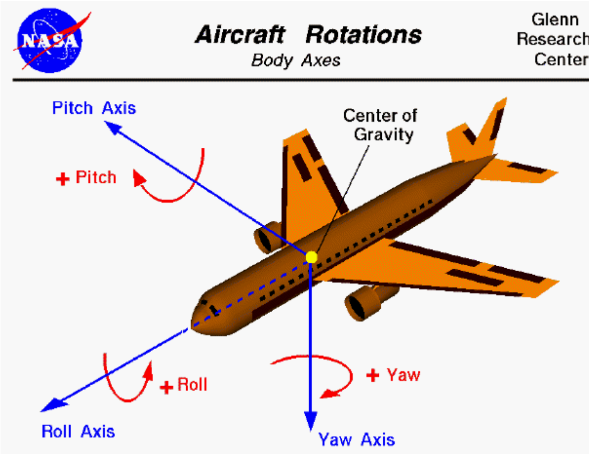
**Fig. 1 (a)** Instrumental flight panel. Adapted from the X-Plane Mobile Manual, X-Plane 10. Retrieved from https://x-plane.com/manuals/mobile/#gettingstarted, 2020.

(1) Airspeed indicator
(2) Attitude indicator
(3) Altimeter
(4) Turn coordinator
(5) Direction gyro
(6) Vertical speed indicator

**Fig. 1 (b)** Controlling a Cessna's pitch, roll and yaw in task 1. Adapted from Aircraft Rotations. Retrieved from https://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/rotations.html, 2020.

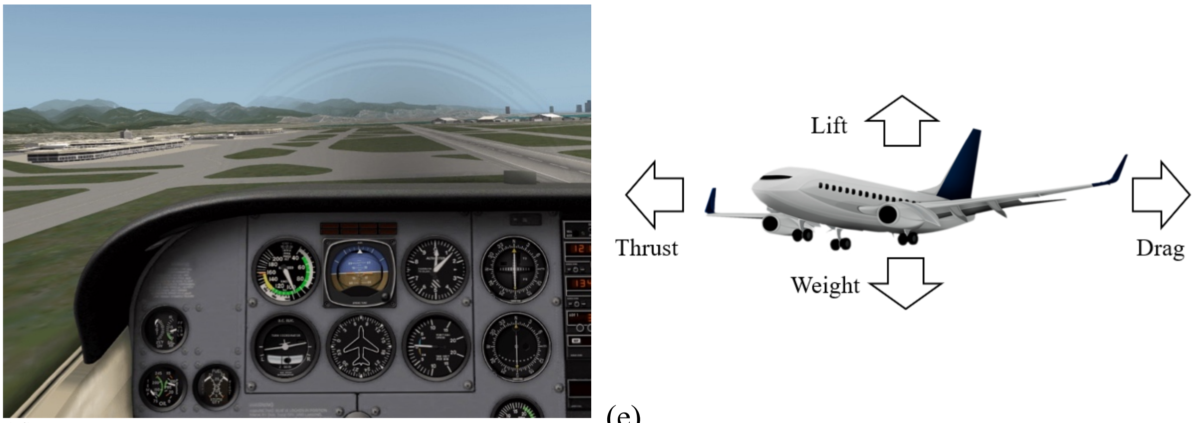
**Fig. 1 (c), (d)** Taking off in a Cessna in task 2 and landing in task 3. Screen-captured from X-Plane 10 Flight School Application.

**Fig. 1 (e)** Force components in a free body diagram of an aeroplane.



(b)

(c)



(d) (e)

## Reliability and Validity of the ASMQ

This section describes the factor analysis used to validate the questionnaire, followed by a correlational analysis of the four motivational constructs, and a multiple regression predicting students' task performance in the flight simulation. After correcting for extreme values and missing data, exploratory factor analysis (EFA) was performed to uncover the motivational patterns and identify the four motivational constructs of science learning. To validate the model's fitness and confirm the hypotheses, confirmatory factor analysis (CFA) was conducted using Amos software.

### *Exploratory factor analysis*

The exploratory factor analysis revealed that the ASMQ had high reliability in measuring motivation in aviation science. As shown in Table 2, Cronbach's alpha ranged from 0.89 to 0.93 (> 0.70), indicating that the ASMQ has a good internal consistency (Feiz & Hooman, 2013). Promax (oblique) rotation was then performed and the sample size was measured using the Kaiser–Meyer–Olkin (KMO) test to confirm that our data were suitable for factor analysis. The results showed that our sample size was good (KMO = 0.963), with significant sphericity (Bartlett's test < 0.000). The correlation matrix was examined for items exhibiting extreme multicollinearity (i.e., $r > 0.90$) (Field, 2013). No extreme multicollinearity was observed.

To ensure reliability, items with substantial differential item functioning (items 7, 13, 15, 19, 25 and 26) were removed when factor loadings constructed in the factor and structure matrices were smaller than 0.4 (Guadagnoli & Velicer, 1988). The factor inclusion criteria were based on eigenvalues greater than 1 and scree plots to find the inflexion point. If two or fewer loaded items were found, they were not considered interpretable (Velicer & Fara, 1998). As such, four constructs were returned to explain about 82.93% of the variance. Amongst them, intrinsic motivation had the largest explanatory power, at 69.92%. The explanatory power rose by 5.23% to reach 75.15% when extrinsic motivation was included. Table 2 details the correlation coefficients and communalities for each construct. This four-factor model identified by the EFA served as the hypothesised model for the subsequent CFA.

**Table 2** Results of exploratory factor analysis

| Construct | Items | Explained Variance | Cronbach's Alpha |
|---|---|---|---|
| *Intrinsic motivation* | 1, 5, 6, 9, 10, 11, 14, 21, 24 | 69.92% | 0.93 |

| | | | |
|---|---|---|---|
| *Extrinsic motivation* | 8, 12, 16, 20 | 5.23% | 0.84 |
| *Peer support* | 27, 28, 29, 30, 31 | 4.58% | 0.91 |
| *Self-efficacy* | 2, 3, 4, 17, 18, 22, 23 | 3.20% | 0.89 |

### *Confirmatory factor analysis*

Confirmatory factor analysis was conducted to evaluate the construct validity of the ASMQ. First, a single-factor model was estimated to test the item's fitness on a unidimensional latent construct. As shown in Table 4, the chi-square result indicated a moderate fit with statistical significance. We then tested the hypothesised four-factor model that emerged from the EFA. However, self-efficacy had to be excluded from the CFA because the covariance matrix for the five factors that include self-efficacy is not definitely positive, thus implying that this model may have a broader multicollinearity problem due to too many key constructs. Thus, we disregarded self-efficacy.

The goodness of fit of the obtained three-factor model was checked. The chi-square coefficient was 908.1 (df = 167, p = .00). Furthermore, given the small sample size, it was advisable to calculate alternative goodness of fit indexes, including the RMSEA, CFI, TLI and SRMR (Brown, 2015). These results were presented in Table 4. Both the CFI (0.924) and TLI (0.912) values were slightly less than 0.95, which meets the criteria for a well-fitting model (Hu & Bentler, 1999). Moreover, the RMSEA (0.086) implied that the model was a good fit for the data, with a cut-off value close to 0.06. The SRMR value (0.00) also indicated a good fit (1999). Internal consistency estimates for the constructs showed that no Cronbach's alphas were less than 0.70, as shown in Table 3. The factor loadings of the items were all above 0.50, so the average variance extracted indicated that the latent construct accounted for at least 50% of the variance (Brown, 2015). Finally, a Pearson's correlation test was conducted to determine the relationships between the dependent variables, as these variables met linearity assumptions (Field, 2013). The correlation between variables was smaller than 0.85, indicating multicollinearity (see Table 5).

**Table 3** Factor loadings and reliability analysis

| **Construct** | **Items** | **Factor Loadings** | **α** | ***M*** | ***SD*** |
|---|---|---|---|---|---|
| *Intrinsic motivation* | 1, 5, 6, 9, 10, 11, 14, 21, 24 | 0.55–0.62 | 0.92 | 3.32 | 0.93 |
| *Extrinsic motivation* | 8, 12, 16, 20 | 0.80–0.88 | 0.84 | 3.11 | 1.01 |
| *Peer support* | 27, 28, 29, 30, 31 | 0.79–0.90 | 0.90 | 3.33 | 0.98 |
| *Self-efficacy* | 2, 3, 4, 17, 18, 22, 23 | - | 0.89 | 3.14 | 0.91 |

**Table 4** Goodness-of-fit indicators

| Model | Chi-square | df | RMSEA | CFI | TLI | SRMR |
|---|---|---|---|---|---|---|
| *Single factor* | 115.2*** | 27 | .097 | .951 | .934 | .037 |
| *Three factors* | 908.1*** | 167 | .086 | .924 | .912 | .000 |

**RMSEA**, root mean square error of approximation; **CFI**, comparative fit index; **TLI**, Tucker-Lewis index; **SRMR**, standardised root mean square residual. ***p < 0.001.

**Table 5** Correlations between motivational constructs

| | 1 | 2 | 3 |
|---|---|---|---|
| **1. Intrinsic motivation** | 1.00 | | |
| **2. Extrinsic motivation** | .758*** | 1.00 | |
| **3. Peer support** | .609*** | .493*** | 1.00 |

Note: $\chi^2_{df=132}$ = 466.6, RMSEA = .00, NNFI = .83, CFI = .856, IFI = .856, RFI = .806; ***p < .001.

## Findings

### *Correlations between motivation, grade, gender and flight performance*

The students exhibited a moderate level of motivation in aviation science, scoring between 2.98 and 3.44 on a 5-point Likert scale. The largest motivator for students was peer support (M = 3.44). The mean scores for each motivation factor and flight performance are presented in Table 6. Pearson correlation was used to examine the inter-relationships between the constructs (see Table 7). Consistent with the theoretical predictions, the correlations between intrinsic motivation, extrinsic motivation, peer support and self-efficacy were all positive, as were the correlations of these four variables with the gender effect and task performance (Aydın, 2015; Walker et al., 2006). No significant differences were found between grade levels.

**Table 6** Descriptive data for each construct

| Construct | M | SD |
|---|---|---|
| Intrinsic motivation | 2.98 | 0.83 |
| Extrinsic motivation | 3.11 | 1.01 |
| Peer support | 3.44 | 1.03 |
| Self-efficacy | 3.14 | 0.91 |
| Performance | 65.96 | 18.20 |

**Note:** The range of possible scores of the constructs lie from 0 to 5.

**Table 7** Correlations between motivational constructs, grade level and flight performance

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1. Intrinsic motivation | 1.00 | | | | | | |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| 2. Extrinsic motivation | .831** | 1.00 |  |  |  |  |  |
| 3. Peer support | .725** | .674** | 1.00 |  |  |  |  |
| 4. Self-efficacy | .857** | .877** | .705** | 1.00 |  |  |  |
| 5. Gender | .530** | .587** | .427** | .611** | 1.00 |  |  |
| 6. Grade level | .008 | .014 | -.27 | -.01 | -.02 | 1.00 |  |
| 7. Performance | .855** | .817** | .887** | .809** | .521** | -.002 | 1.00 |

** p < .01

***Motivation across gender, low and high-performance groups***

MANOVA was used to analyse the motivational pattern across gender and performance groups. Wilks' lambda revealed that the motivation constructs were significantly associated with students' learning outcomes (F = 72.05, p < 0.001) and gender (F = 21.48, p < 0.001). However, there was no significant interaction effect between the two independent variables (F = 1.13, p > 0.05). The students' intrinsic motivation, extrinsic motivation, peer support and self-efficacy were found to be significantly dependent on their learning performance and had different effect sizes (*F*). For example, peer support was significantly dependent on flying performance, with F = 5.61 and p < 0.05. In addition, the results show that the girls in the sample tended to have lower intrinsic and extrinsic motivation, self-efficacy and peer support than the boys (see Table 8). As Table 8 shows, intrinsic and extrinsic motivation and peer support were more influential than self-efficacy in engaging female students in the flight simulation environment, as the Cronbach's alpha of 4.05 was slightly higher than those of the other three motivational constructs. In addition, the students who obtained an above-average flight performance tended to have greater motivation. This is understandable, because high-achieving learners typically have higher learning goals and expectations of themselves (Ee, Moore & Atputhasamy, 2003).

**Table 8** Levels of STEM motivational factors across performance and gender

| **Constructs** | **Low Performer** |  | **High Performer** |  | **Gender** | **Performance** | Gender* Performance |
|---|---|---|---|---|---|---|---|
|  | *Male* | *Female* | *Male* | *Female* | *F* | *F* | *F* |
| ***1.*** *Intrinsic motivation* | 2.67 | 2.32 | 3.69 | 3.17 | 38.62** | 181.97** | 1.52 |
| ***2.*** *Extrinsic motivation* | 2.88 | 2.29 | 4.00 | 3.18 | 70.50** | 142.44** | 1.86 |
| ***3.*** *Peer support* | 2.81 | 2.64 | 4.27 | 4.05 | 5.61* | 296.40** | 1.32 |
| ***4.*** *Self-efficacy* | 2.91 | 2.40 | 3.99 | 3.16 | 85.56** | 159.55** | 4.66* |

** p < .01, *p < .05

**Note:** The range of possible scores of the constructs lie from 0 to 5 for low and high performer groups. F-test demonstrates that the effects of gender and performance are statistically significant different between the two groups.

### *Multiple regression analysis*

To examine how well the three constructs predicted students' learning outcomes, we conducted a multiple regression analysis. The null hypothesis was that no relationship exists between the motivational predictors and flying performance. The alternative hypothesis was that a significant relationship exists between the motivational constructs and the learning outcome.

The students' predicted flying performance was equal to 9.38 peer support + 6.32 intrinsic motivation + 3.97 extrinsic motivation + 2.57. The structural equation suggested that peer support and intrinsic motivation can successfully encourage learning performance (see Table 9). Around 90% of the variation in performance could be explained by this model (R-square = 0.90; p = .00). The sample was further divided into two groups: above-average and below-average flying performance. Similar regression results were found (R-square 0.744 and 0.727 for the lower and higher performers, respectively; see Tables 10 and 11). Around 74.4% and 72.7% of the variation from the lower and higher performers can be explained by this model. This result is aligned with the ANOVA test, which shows that such regression equations are significant enough to predict students' flying performance (p = .00). We also denoted the associations between the three motivational constructs across the high and low performance groups (see Table 12).

The multiple regression analysis revealed that peer support was the most important predictor of learning outcomes for both the higher- and lower-performing groups, and intrinsic motivation was the second most important motivator. One possible reason is that the flight simulation exercise was associated with classroom interaction, which is consistent with empirical studies. Peer support and classroom interaction play prominent roles in stimulating students' cognitive engagement in science learning (Chen, Wang & Lin, 2010; Hakkarainen, 2003; Zoldosova & Prokop, 2006). To explain the second predictor, a great deal of research supports aviation as a stimulus to raise students' intrinsic motivation towards STEM learning. This phenomenon can be attributed to the persistence of interest arising from engaging elements incorporating fun, challenge and competition (Malone, 1980) that kindle children's intrinsic motivation and innate curiosity through design, making and play (Honey & Kanter, 2013). Finally, extrinsic motivation was the least strong predictor of performance for both the lower- and higher-level performers. This suggests that the students tended to feel efficacious throughout the flight simulation tasks, but not because of external rewards from teachers and other students, grade reinforcement, or avoiding being laughed at when they failed (Lee et al., 2016).

**Table 9** Overall multiple regression analysis

**Learning outcome = 9.38 peer support + 6.32 intrinsic motivation + 3.97 extrinsic motivation + 2.57**

| Model | Estimate | Standard error | *t* | Significance level |
|---|---|---|---|---|
| 1 (constant) | 11.93 | 1.58 | 7.55 | .000 |
| Peer support | 15.69 | .44 | 35.67 | .000 |
| 2 (constant) | 2.47 | 1.31 | 1.89 | .060 |
| Peer support | 9.97 | .47 | 20.91 | .000 |
| Intrinsic motivation | 9.81 | .59 | 16.58 | .000 |
| 3 (constant) | 2.57 | 1.29 | 2.09 | .037 |
| Peer support | 9.38 | .46 | 20.62 | .000 |
| Intrinsic motivation | 6.32 | .75 | 8.41 | .000 |
| Extrinsic motivation | 3.97 | .57 | 6.92 | .000 |

**Table 10** Multiple regression analysis for the high-performance group

**Model for the high-performance group:**
**Learning outcome = 7.52 peer support + 5.71 intrinsic motivation + 3.27 extrinsic motivation + 16.70**

| Model | Estimate | Standard error | *t* | Significance level |
|---|---|---|---|---|
| 1 (constant) | 36.72 | 3.29 | 11.16 | .000 |
| Intrinsic motivation | 12.47 | .91 | 13.64 | .000 |
| 2 (constant) | 17.34 | 3.26 | 5.32 | .000 |
| Intrinsic motivation | 8.90 | .81 | 10.97 | .000 |
| Peer support | 7.62 | .76 | 9.97 | .000 |
| 3 (constant) | 16.70 | 3.11 | 5.35 | .000 |
| Peer support | 5.71 | 1.08 | 5.24 | .000 |
| Intrinsic motivation | 7.52 | .73 | 10.31 | .000 |
| Extrinsic motivation | 3.27 | .79 | 4.15 | .000 |

**Table 11** Multiple regression analysis for the low-performance group

**Model for the low-performance group:**
**Learning outcome = 7.51 peer support + 5.20 intrinsic motivation + 3.22 extrinsic motivation + 10.59**

| Model | Estimate | Standard error | *t* | Significance level |
|---|---|---|---|---|
| 1 (constant) | 22.74 | 1.98 | 11.48 | .000 |
| Peer support | 10.56 | .71 | 14.82 | .000 |
| 2 (constant) | 12.00 | 1.96 | 6.11 | .000 |
| Peer support | 7.91 | .64 | 12.32 | .000 |
| Intrinsic motivation | 7.42 | .78 | 9.51 | .000 |
| 3 (constant) | 10.59 | 1.89 | 5.60 | .000 |
| Peer support | 7.51 | .62 | 12.18 | .000 |
| Intrinsic motivation | 5.20 | .90 | 5.79 | .000 |
| Extrinsic motivation | 3.22 | .73 | 4.41 | .000 |

**Table 12** Multi-group analysis for the low- and high-performance groups

| | **Low-performance group** | | | **High-performance group** | | |
|---|---|---|---|---|---|---|
| | Intrinsic motivation | Extrinsic motivation | Peer support | Intrinsic motivation | Extrinsic motivation | Peer support |
| **Intrinsic motivation** | 1.00 | | | 1.00 | | |
| **Extrinsic motivation** | .254** | 1.00 | | .303** | 1.00 | |
| **Peer support** | .207** | .116** | 1.00 | .143** | .081** | 1.00 |

** p < .01

## Discussion and Implications

The purpose of this study was to determine the relationships between intrinsic motivation, extrinsic motivation, self-efficacy and peer support across gender and performance ability, and to construct a regression model to predict the task performance of upper primary students in a flight simulation environment. The results suggest an inter-correlation pattern between the four motivational constructs that directly affect student performance. The regression model identifies peer support as the most important factor influencing performance, and intrinsic motivation and self-efficacy were found to be the second and third motivators. As expected, a gender gap was found in STEM learning with the focus on aviation. These results may help educators to design STEM activities that take account of factors that promote students' motivation. A set of teaching practices are suggested, and four implications are outlined below.

### *Using a technology-enhanced collaborative approach to enhance peer support*

Our findings suggest that peer support and intrinsic motivation are successful predictors of flying performance for upper primary students. Peer support had the greatest factor loading in the CFA and was the highest motivator in the multiple linear regression. This result is consistent with the findings of prior studies. A meta-analysis conducted by Jeong, Hmelo-Silver and Jo (2017) presented results showing the effectiveness of computer-supported collaborative learning, based on 2,669 studies published from 2005 to 2014 for K-12 and higher education. The studies were assessed against the following criteria: (a) empirical research on STEM education, (b) randomised or quasi-experimental design and (c) learning outcome analysis (e.g., attitude, cognitive gains, processes or non-cognitive outcomes). From this screening, 143 independent studies were identified, and based on these studies and their prior study (Jeong & Hmelo-Silver, 2016), the authors proposed the following recommendations for collaborative learning environments: providing tools for communication, collaborative tasks, structuring the collaborative learning process, facilitating the sharing and creation of resources, supporting knowledge, co-construction and intersubjectivity, helping with monitoring and regulation and forming groups and communities.

Other studies have also illustrated the benefits of an interactive and collaborative approach in science learning at elementary level. Topping et al. (2004) found positive cognitive and affective gains from peer tutoring in a 'paired science' programme: hands-on activities with interactive discussion and feedback effectively enhanced deeper understanding and transferable skills in science contexts amongst 7- to 9-year-old primary students. Moreover, game-based science learning engaged grade 7 students in exploring science concepts explicitly and mindfully, and when supplemented with collaborative learning could enrich students' learning experience and collective problem solving (Chen, Wang & Lin, 2010). Hakkarainen (2003) revealed that primary students can be guided to engage in processes of inquiry to approach problems being investigated at deepening levels of explanation in a computer-supported learning environment over two years. Song (2018) designed project-based learning about plant adaptations to develop collaborative problem-solving competency in science learning in a seamless learning environment for grade 6 students. So and Ching (2011) designed a collaborative science learning environment for science inquiry at primary schools to engage pupils in a scaffolded active thinking and talking process. These studies suggest that computer-supported collaborative activities can effectively facilitate children's science learning.

### *Making, design and inquiry to spark intrinsic motivation*

Intrinsic motivation was found to be the second highest motivator in the regression model. This result implies that teachers should incorporate fun, challenges, design, competitions, making and games that take account of learners' diversity and motivate students to learn for their own sake (Malone, 1980; Hongey & Kanter, 2013). Bomia et al. (1997) reviewed a set of motivational strategies to influence students' intrinsic motivation: assigning projects that provide practical applications of learning, clarify requirements for success in tasks and provide timely and corrective feedback. Thus, the design of a scenario-based flight simulation can offer students a gamified and engaging experience in which they perform flying operations and procedures in various scenarios with effective automatic feedback from the simulator (Goodhew, 2010).

Evidence suggests that educators can integrate digital technologies to kindle students' intrinsic motivation and their understanding of aviation through science inquiry (English & King, 2015; Ke & Carafano, 2016; Texley, 2007, p. 69; Watters & Christensen, 2014). Science inquiry should be adopted to facilitate primary students' learning about how ideas can be transformed into science understanding and further questioning (Wu & Hsieh, 2006). Through flight simulation processes, teachers first raise scientifically oriented questions such as 'Why do jet airliners, Cessnas and gliders have different wing designs?' and 'What is the similarity between a spoiler and a plane's wing design?' These questions promote students' inquiry and help transform their basic knowledge and understanding (Murdock, 2017). Then, students gather evidences such as comparing flight characteristics between airplanes with varied wing designs, lowering spoilers to increase a drag. This way, students can formulate explanations to connect to scientific knowledge especially in physics that they have learnt. Most important is students' curiosity about open-ended investigations of asking good questions or problems. Although some of these concepts may not be covered in the formal upper-primary curriculum, educators can raise meaningful questions and thus connect them to students' prior understanding, helping them to arrive at more sophisticated concepts. These findings can help educators increase the intrinsic motivation of students through engaging with technology-enhanced tools and science inquiry. This can encourage students to actively participate in STEM-related learning.

### *Confidence in prior knowledge and self-efficacy*

Our CFA results indicate that when considering senior primary school students' STEM learning motivation in the theoretical framework, self-efficacy cannot be loaded as expected in the modified MSLQ-RCV. An individual's self-efficacy is defined as their possession of the capabilities necessary to perform a task successfully (Bandura, 1986). It is not common for primary students to have past experience or prior knowledge of aviation, and these students had not used a flight simulator before. Past performance is a great contributor to students' confidence (1986). If students have a successful experience with a task, they tend to believe that they can perform well in the same or similar tasks in the future. The students in this study could not form an expectation based on previous experience of learning about this new topic, aviation science. When a student sees other students accomplish a flying task, the vicarious experience of observing a model may influence their self-efficacy. By observing others like themselves perform tasks, students make judgements about their own capabilities. Although self-efficacy did not load as expected in the model, the literature has suggested that teachers should continue to broaden students' horizons and engage them in new learning experiences so that they adapt to new concepts and believe in their ability to complete a new task.

### *A feminist and collaborative approach to engage girls in aviation learning*

Our empirical study suggests that there are significant gender differences in aviation learning and that girls are likely to show poorer flying performance than boys, indicating the need to encourage and support girls in STEM learning. This is consistent with the previous finding that a gender performance gap exists because female students tend to have lower motivation and poorer learning outcomes in STEM fields at different ages (Hill, Corbett & St Rose, 2010) and hence hold a disproportionately low proportion of STEM academic qualifications and workforce positions (Beede, 2011). Women trainees in the aviation industry have also been found to have lower flight performance records than men, which may be attributable to their gender-stereotypical perceptions of careers in aviation (Lutte, 2019). However, women are vital for meeting global personnel requirements: 74.9% of cabin attendants are female, but only 5.2% of pilots are female in Western countries, along with only 13.4% of engineers (Lutte, 2019).

Beede (2011) noted many possible reasons for such gender differences, including a lack of female role models, gender stereotyping and less family-friendly flexibility in STEM fields. Wang and Degol (2017) proposed six explanations for US women's underrepresentation in maths-intensive STEM fields: (a) cognitive ability, (b) relative cognitive strengths, (c) occupational interests or preferences, (d) lifestyle values or work–family balance preferences, (e) field-specific ability beliefs, and (f) gender-related stereotypes and biases. Developmental research indicates that children as young as 2nd grade more strongly associate maths with boys than girls (Cvencek et al., 2011). Other authors have proposed that 'stereotype threat' can undermine girls' interest and performance in STEM domains (Shapiro & Williams, 2012). Margolis, Fisher and Miller (2000) found that female students lost interest in STEM subjects because they felt that they lacked supportive and close bonds with other students.

A common technique for reforming science education is to transform how students learn by implementing collaborative approaches to learning in the classroom (Crosnoe et al., 2008; Chen et al., 2009). The underrepresentation of girls in science has encouraged many K-12 educators to develop collaborative and feminist pedagogies to tackle gender disparity and influence students' motivation by satisfying the psychological needs of girls. Mayberry (1998) suggested a feminist pedagogy, in which students are introduced to famous women scientists and engineers to reduce gender differences in the discourse of science. These studies provide evidence that can help educators use collaborative strategies to engage girls in studying aviation and other STEM-related subjects.

## Limitations and Future Research

Due to the nature of this study, caution should be taken when generalising the findings to other grade levels and subject disciplines. A wider variety of flight simulation conditions should be trialled, such as flying circuits and route planning. Due to the limited time available for the project, the students could only experience three scenarios during the flight simulation activity. However, the results of this study support previous findings concerning motivations for learning about aviation. Future studies could examine how other digital technologies, such as unmanned aerial systems and virtual reality, can motivate students' STEM learning with a focus on aviation.

Another important direction for future research relates to the transferability of the questionnaire. One limitation of the study is whether students' motivation in aviation learning could be transferred to other science disciplines in general, or at least to closely related ones such as physics. To generalise motivational patterns to other science disciplines or other concepts in aviation, a future study could examine how students' motivation to learn science changes with their knowledge construction. As peer support and intrinsic motivation are the two most important motivational constructs, teachers could design and implement interesting and collaborative aviation-themed activities, programmes and competitions.

Third, the novelty effect of integrating flight simulation for student participants was not considered. Although many teachers stimulate students' STEM interest by inciting curiosity and introducing novelty in technological contexts (e.g., makerspace, virtual reality, chatbots, gamification, the new science curriculum), these approaches were not addressed in detail in this study (Hudson et al., 2015; Chittum et al., 2017).

Future research could be conducted in primary and secondary schools to examine what factors contribute to losing the motivation to learn STEM, how students' motivation can be improved and which activities are most meaningful to students. Longitudinal studies could address these questions in greater depth in conjunction with qualitative methods.

## Conclusion

The 'fun of flying' encourages children to reach new heights of knowledge through aviation-themed STEM activities and gives them an alternative approach to learning about concepts that cut across academic disciplines. Our research results show that there is a significant inter-correlated pattern of intrinsic and extrinsic motivation, peer support and self-efficacy amongst upper primary students. Furthermore, based on regression and factor analysis, students are most strongly motivated by peer support, followed by intrinsic motivation, and they are least motivated by self-efficacy throughout engaging flight simulation activities amongst senior primary students. Girls also appear to be underrepresented in aviation learning, and they tend to have lower motivation and achieve lower flying performance than boys.

By understanding what can motivate students and how, the current study provides learning insights for STEM educators, who can use theme-based teaching strategies to enrich the curriculum and enhance students' intrinsic motivation through computer-supported collaborative activities. Aviation learning is worthy of inclusion in the K-12 STEM curriculum to encourage students to study science and maths, and to pursue their academic and career potential. Other aviation learning activities, such as drone operation, radio communication and air traffic management, can also help students enrich and apply their interdisciplinary knowledge of computer programming, geography and language. Based on the findings of this study, the following teaching practices are suggested.

- As most upper-primary students have not tried flight simulation before, it is recommended that science teachers should be given training before applying it in the classroom.
- Intrinsic motivations were found to affect learning outcomes, so educators are advised to choose suitable aviation-themed activities to capture students' attention, using elements such as challenge, fantasy, control, curiosity, cooperation, recognition and competition.
- Teachers can use simulation technology to help students visualise scientific phenomena and consolidate science concepts, and to develop their problem-solving skills.
- To ensure that students benefit from the important factor of peer support, educators should encourage them to conduct scientific inquiries through peer learning, as this can enhance their science understanding and transferrable skills (e.g., communication, problem solving and teamwork). Students can communicate and justify explanations together with teammates, thus connecting their explanations to physics concepts that they have learnt.
- Our findings confirm that gender disparity is an issue in aviation learning. In male-dominated disciplines such as computing, engineering and aviation, educators should consider all students' learning needs and use feminist and collaborative pedagogy.
- Both higher and below-average performers were found to be affected by intrinsic motivation and peer support. To develop the learning styles and thinking of all students, educators should encourage high achievers to help others in the classroom through a collaborative approach.
- Although applications are developed based on real-life scenarios and scientific phenomena, educators should raise inquiry-based questions such as 'Why do jet airliners, Cessnas and gliders have different wing designs?' and 'What is the similarity between a spoiler and a

plane's wing design?' These questions can help students link science concepts to other scenarios.

- Flight simulators can range from single-screen versions to research simulators with realistic cockpit layouts, but simple low-cost flight simulation devices are sufficient to encourage students' interest and consolidate general physics concepts.
- As K-12 educators do not aim to train primary students in piloting, sophisticated audio, visual and haptic sensory immersion may not be very useful (Ke & Carafano, 2016) and may even hinder the understanding and motivations of beginners. Educators should not blindly follow technology, but should link pedagogy with content knowledge and technology.

## Compliance with Ethical Standards

1. Disclosure of potential conflicts of interests

The authors declare that they have no conflict of interest.

2. Ethical statement

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

3. Consent statement

Informed consent was obtained from all individual participants included in the study.

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**Appendix 1.** Details of selected articles related to STEM learning with a focus on aviation

| | Study | Journal/ Presentation | Publisher | Method | Educational level | Categories |
|---|---|---|---|---|---|---|
| 1 | Strickler (1994) | FAA Report Federation History | FAA | Report | K-12 | K-12 curriculum |
| 2 | Kraus (2014) | | | | | |
| 3 | Pols, Rogers & Miaoulis (1994) | Journal of Engineering Education | Wiley | Qualitative student feedback | Middle school | K-12 curriculum, science activities, programme evaluation |
| 4 | Abbitt et al. (1996) | | | Qualitative case study | Higher education | Programme evaluation, university engineering, adult learning |
| 5 | Koh et al. (2010) | | | MANOVA, descriptive analysis | Higher education | Simulation-based learning, motivation, self-determination theory, adult learning |
| 6 | Eberhardt (2000) | | | Qualitative case study | Higher education | Engineering curriculum, non-engineering students |
| 7 | Ke & Carafano (2016) | Computer & Education | Elsevier | Qualitative observation, knowledge test, STEM attitudes survey | High school (Grades 9–10) | Immersion, flight simulation, computer supported collaborative learning, simulation-based learning |
| 8 | Rawat, Lawrence, Mangham & Gooden (2018) | Annual Conference & Exposition | American Society for Engineering Education | Descriptive analysis | K-12, middle & high school | Out-of-school learning, K-12 STEM activities, student feedback survey, gender dispersity, career interest, technology-enhanced learning |
| 9 | Aji & Khan (2018) | | | Quasi-experimental research | K-12, middle school | K-12 STEM education, flight simulation, maths and science learning |
| 10 | Hill, Lee & Gadsden (2018) | | | Case study | K-12, high school | K-12 STEM education, lesson study |
| 11 | Khan et al. (2012) | South Section Conference | | Survey | K-12, middle school | K-12 STEM education, flight simulation, maths and science learning, lesson plans |
| 12 | Farr & Light (2019) | IEEE Integrated STEM Education Conference | IEEE | Case study | K-12, middle and high school | Drone education, K-12 education, engineering design process, creative problem-solving, competency-based learning |
| 13 | Pietsch, Bohland & Schmale (2015) | Journal of Biological Education | Routledge | Case study | K-12, high school | Biological flight, aerodynamic principles, K-12 STEM education |
| 14 | Saastamoinen & Rissanen (2019) | Journal of Physics: Conference Series | IOP Publishing | Action research, case study, survey | High school | K-12 STEM education, flight simulation, physics education |

| | | | | | | |
|---|---|---|---|---|---|---|
| 15 | Surra & Litowitz (2014) | Technology & Engineering Teacher | International Technology & Engineering Educators Association | Qualitative case study | High school | K-12 STEM activities, teacher reflection |
| 16 | Texley (2007) | Science Scope | JSTOR | Review | K-12 | K-12 STEM activities, technology-based inquiry |
| 17 | English & King (2015) | International Journal of STEM Education | Springer | Qualitative case study | Grades 4–6 | Engineering design process of model planes |
| 18 | Wood (2013) | Mathematics Teaching in the Middle School | JSTOR | Article | K-12, elementary, middle and high school | Maths attitude, simulation-based learning |
| 19 | Watters & Christensen (2014) | Proceedings of the ESERA 2013 Conference | Cyprus | Qualitative case study | Grades 8–12 | Vocation education, K-12 curriculum |
| 20 | Secer & Sahin (2013) | International Journal on New Trends in Education and Their Implications | IJNOTE | Group focus interview | Grades 10–11 | Aviation English, radio phraseology |
| 21 | Karp (2018) | The Collegiate Aviation Review International | Open Journal Systems | Review | Higher education | Adult learning, learning style, motivation |
| 22 | Hubbard & Lopp (2015) | Journal of Education & Human Development | American Research Institute for Policy Development | Qualitative case study | Higher education | STEM education, industry engagement, practical based learning |
| 23 | Aji & Khan (2015) | Journal of College Teaching & Learning | Clute Institute | Qualitative case study | Higher education | Unmanned aerial system, flight simulation, adult learning |
| 24 | Allan et al. (2018) | Proceedings of International Conference on Information, Communication Technologies in Education (ICICTE) | ICICTE | Design-based research | Higher education | Adult learning, blended learning |
| 25 | DiLisi, McMillin & Virostek (2011) | Journal of STEM Education: Innovations and Research | The Institute for STEM Education and Research | Survey, qualitative programme evaluation | K-12 | Women in aviation, community service, flight-simulation, programme evaluation |
| 26 | Bollock & Belt (2020) | Collegiate Aviation Review International | University Aviation Association | Survey, case study | K-12 | Aviation out-of-school programme |

## **Appendix 2.** Translated English-Version of Science Motivation Questionnaire (Aviation)

To better understand what you think and feel about your science courses, please respond to each of the following statements from the perspective of 'When I am in an aviation STEM workshop…'

Gender: M / F

Grade level: P.4 / P.5 / P.6

Highest Game Score: _____/100

Please respond to the following statements based on the 5-point scale below.

Never Rarely Sometimes Usually Always

1. I think that what we are learning in the flight simulation workshop is interesting.
2. Compared with other students in this virtual flying workshop, I expect to do well.
3. Compared with others in the class, I think I am a good student. I am sure I will do an excellent job in the flying tasks.
4. My study skills are excellent compared with others in the flight simulation workshop.
5. I think what I am learning in the flight simulation workshop is useful for me to know.
6. Even if I do poorly in a flying task, I will try to learn from my mistakes.
7. If I do well in the flight simulation workshop, it will help me in my future career.
8. I want to do well in the flight simulation workshop because it is important to show my abilities to my family, friends, or others.
9. I think that I will be able to use what I learn in one subject in another.
10. I like what I am learning in the flying tasks.
11. I prefer the flying task because it is challenging so I can learn new things.
12. If I can, I want to do better in the flight simulation workshop than most of the other students.
13. Flight simulation can enhance students' interaction.
14. It is important for me to learn what is being taught in the flight simulation workshop.
15. Understanding aviation science will benefit me in my career.
16. Getting a good grade in the flight simulation workshop is the most satisfying thing for me right now.
17. I know that I will be able to learn the materials for the flying tasks.
18. I am certain that I can understand the science concepts in the flight simulation workshop.
19. I can learn and solve the flying problems with my classmates.
20. The most important thing for me right now is improving my score in the flying tasks, so my main concern in this workshop is getting a good grade.
21. Understanding aviation science is important to me.
22. I think I will receive good grades in the flying tasks.
23. I am sure I can do an excellent job in the flying tasks.
24. I often do more than is required of me in the flying tasks.
25. I am interested in careers that use science.
26. I will use science problem-solving skills in my future career.
27. When I encounter difficulties in the workshop, I ask my instructors or classmates questions.
28. I discuss issues and interact with my classmates during the workshop.
29. I can complete flying tasks with my classmates.