



## Effective Air Traffic Control Learning: New Approaches and Innovative Methods

Ridho Rinaldi<sup>1\*</sup>, Dimas Arya Soeadyfa<sup>2</sup>, Wasito Utomo<sup>3</sup>  
Politeknik Penerbangan Surabaya

**Corresponding Author:** Ridho Rinaldi [ridhoatkp@gmail.com](mailto:ridhoatkp@gmail.com)

---

### ARTICLE INFO

*Keywords:* ATC Learning, Innovative Learning Methods, Learning Effectiveness Factors, Simulation in ATC, VR/AR in Training

*Received :* 13 August

*Revised :* 01 September

*Accepted:* 03 October

©2024 Rinaldi, Soedyfa, Utomo:

This is an open-access article distributed under the terms of the

[Creative Commons Atribusi 4.0](https://creativecommons.org/licenses/by/4.0/)

[Internasional](https://creativecommons.org/licenses/by/4.0/).



### ABSTRACT

This research discusses more effective Air Traffic Control (ATC) learning through new approaches and innovative methods. The new approaches described include project-based, problem-based, skill-based, and game-based approaches. Meanwhile, the innovative methods discussed include simulation, virtual reality (VR), and augmented reality (AR). Factors that influence the effectiveness of ATC learning are also discussed, including the ability of instructors, facilities, and student motivation. This research used qualitative methods by conducting interviews with 10 ATC personnel and 10 ATC instructors, and performing a Two Sample Mean Test on 96 ATC students in Indonesia. Based on the analysis, it was found that innovative methods and new approaches can improve the effectiveness of ATC learning compared to Conventional methods. However, further research is needed to deepen the use of technology in ATC learning.

---

## INTRODUCTION

Air Traffic Control (ATC) is a crucial aspect of the aviation industry. Air traffic controllers are responsible for ensuring the safety of aircraft and passengers in the air (Gordon, Kirwan, and Perrin 2007). To become an air traffic controller, one must undergo extensive training and learn various complex concepts and procedures. ATC learning is usually done through formal courses in aviation schools or on-the-job training (Koskela and Palukka 2011). However, the learning process is not always easy, especially for students who are new to this profession. Some students may have difficulty understanding complex concepts and procedures, while others may become bored with monotonous learning methods.

To address this problem, innovation in learning methods is needed to improve the effectiveness of ATC learning. More interactive and practical learning can help students better understand concepts and procedures, as well as enhance their ability to handle real-world situations (Fothergill, Loft, and Neal 2009). Several innovative learning methods that can be applied to ATC learning include simulation (Loft et al., 2004, Di Stasi et al., 2010, Bauer & Langr, 2017), virtual and augmented reality technology (Reisman & Brown, 2006, Vinot et al., 2014, Masotti et al., 2016, Gorbunov & Nechaev, 2022). These innovative learning methods not only improve the effectiveness of learning but also prepare students with better and up-to-date skills that can help them in their future careers (Soldatov et al. 2018).

Therefore, this article aims to review various effective and innovative learning methods that can be applied to ATC learning. This article is expected to help overcome problems in learning and improve the quality of education and the ability of air traffic controllers, thus helping to create a safer and more efficient aviation world.

## LITERATUR REVIEW

### **Constructivist Learning Theory**

Constructivist Learning Theory suggests that learners actively construct their own understanding and knowledge through experiences and reflection. In Air Traffic Control (ATC) learning, this theory supports the use of active, hands-on learning methods such as project-based, problem-based, skill-based, and game-based approaches. These methods encourage students to engage with real-world scenarios, promoting critical thinking, problem-solving, and the application of knowledge in practical situations, thereby enhancing their overall learning effectiveness. Previous research supports this hypothesis, indicating that such active learning approaches result in deeper understanding, better retention, and enhanced ability to apply knowledge in dynamic and complex environments like ATC (Hmelo-Silver, 2004; Sitzmann, 2011).

H1: The integration of project-based, problem-based, skill-based, and game-based learning methods in ATC training leads to improved learning outcomes compared to traditional lecture-based methods.

### **Cognitive Load Theory**

Cognitive Load Theory posits that the human brain has a limited capacity for processing information, and learning is most effective when instructional design minimizes unnecessary cognitive load. In the context of ATC learning, where information is complex and abundant, innovative methods like simulation, Virtual Reality (VR), and Augmented Reality (AR) can help manage cognitive load by offering immersive and interactive environments that allow learners to practice and refine their skills without the risk of real-world errors. Studies have demonstrated that these technologies provide realistic, immersive experiences that improve spatial awareness, decision-making, and overall learning outcomes by reducing the cognitive effort required to understand complex scenarios (Mayer & Moreno, 2003; Lin & Wang, 2012).

H2: The use of simulation, VR, and AR in ATC training reduces cognitive load and enhances the effectiveness of learning compared to conventional training methods.

### **Self-Determination Theory**

Self-Determination Theory (SDT) focuses on the role of motivation in learning, positing that individuals are more likely to engage in and benefit from learning activities when they experience autonomy, competence, and relatedness. In ATC learning, this theory suggests that methods fostering student motivation – such as game-based learning and the use of VR/AR, which provide autonomy through interactive and self-directed learning environments – can lead to more effective learning outcomes. Research has shown that when learners are motivated and feel in control of their learning, they are more engaged, which leads to better performance and retention of knowledge (Ryan & Deci, 2000; Papastergiou, 2009). This is particularly relevant in high-stress fields like ATC, where motivation is crucial for effective learning.

H3: The incorporation of game-based learning and VR/AR technologies in ATC training enhances student motivation and improves learning outcomes compared to traditional methods.

### **Contextual Framework**

The contextual framework of this research integrates the Constructivist Learning Theory, Cognitive Load Theory, and Self-Determination Theory to explore the effectiveness of new approaches and innovative methods in ATC learning. This framework examines how active learning methods (grounded in constructivist principles), immersive technologies (aligned with cognitive load management), and motivational strategies (based on SDT) collectively contribute to enhanced learning outcomes in ATC training. The framework also considers external factors such as instructor quality, facility availability, and student motivation, which influence the overall effectiveness of these educational interventions.

## METHODOLOGY

Air Traffic Control (ATC) is a crucial aspect of the aviation industry. Air traffic controllers are responsible for ensuring the safety of aircraft and passengers in the air (Gordon, Kirwan, and Perrin 2007). To become an air traffic controller, one must undergo extensive training and learn various complex concepts and procedures. ATC learning is usually done through formal courses in aviation schools or on-the-job training (Koskela and Palukka 2011). However, the learning process is not always easy, especially for students who are new to this profession. Some students may have difficulty understanding complex concepts and procedures, while others may become bored with monotonous learning methods.

To address this problem, innovation in learning methods is needed to improve the effectiveness of ATC learning. More interactive and practical learning can help students better understand concepts and procedures, as well as enhance their ability to handle real-world situations (Fothergill, Loft, and Neal 2009). Several innovative learning methods that can be applied to ATC learning include simulation (Loft et al., 2004, Di Stasi et al., 2010, Bauer & Langr, 2017), virtual and augmented reality technology (Reisman & Brown, 2006, Vinot et al., 2014, Masotti et al., 2016, Gorbunov & Nechaev, 2022). These innovative learning methods not only improve the effectiveness of learning but also prepare students with better and up-to-date skills that can help them in their future careers (Soldatov et al. 2018).

Therefore, this article aims to review various effective and innovative learning methods that can be applied to ATC learning. This article is expected to help overcome problems in learning and improve the quality of education and the ability of air traffic controllers, thus helping to create a safer and more efficient aviation world.

## RESULTS

Conventional Air Traffic Control (ATC) learning refers to the teaching and training methods used to impart basic knowledge and skills required by air traffic controllers. This training typically consists of theoretical and practical lessons taught in a classroom and ATC training center environment. Conventional ATC training usually covers a range of topics including knowledge of navigation (Grishin and Timirgaleeva 2017), meteorology (Trub et al. 2018), flight systems, air traffic regulations, and basic principles of air traffic control. In addition, ATC students are trained in communication skills with pilots and ground personnel through radio and telephone (Kendall-Taylor et al., 2013, Strohmeier et al., 2019, Lin, 2021).

At an advanced level, ATC training may involve flight simulation using sophisticated flight simulators. These simulations teach air traffic controllers how to handle complex situations such as bad weather, communication equipment disruptions, or aircraft accidents. ATC students are also trained to use advanced technologies such as radar and satellite navigation systems to monitor and control flights. Moreover, ATC training also includes work practices in actual air traffic control centers, where students can monitor and control flights directly under the guidance of experienced air traffic controllers

**Table 1. Conventional Air Traffic Control Learning Activities**

Conventional ATC Learning Activities	Description of Activities
Theory Lessons	Learning theory related to navigation, meteorology, aviation systems, and air traffic regulations
Practice Lessons	Learning practical skills related to air traffic control and communication with pilots and ground personnel
Simulation	Training in air traffic control simulation using conventional laboratory.
Internship at Air Traffic Control Centers	On-the-job training at actual air traffic control centers to monitor and control air traffic
Assessment and Exams	Evaluation and exams to measure students' ability to control air traffic and ensure aviation safety

In conventional learning practical training, the simulation used usually involves an ATC Manual laboratory consisting of a miniature aerodrome layout, miniature aircraft, and aircraft movements that require manual assistance from students, so the aircraft cannot maneuver, the speed of the aircraft, weather conditions, and emergency situation training is not like in actual situations. This also hinders the knowledge and skills of students in controlling air traffic. However, the advantage of conventional training is that it does not require a lot of equipment as it only uses a pictorial airport layout board, and practical costs are relatively cheap.



**Figure 1. Conventional Air Traffic Control Practical Learning**

Interviews with air traffic control personnel and instructors indicate that conventional learning methods do not maximize students' understanding of air traffic control simulations due to limited practical experience and the inability to replicate real-world conditions, such as weather changes and actual aircraft movements. Additionally, the inflexible schedules and curricula of conventional training hinder adaptation to individual student needs and emerging aviation trends. Resource constraints at ATC training centers further limit accessibility for all students. Moreover, a strong emphasis on traditional ATC methods may result in gaps regarding newer technological advancements in the aviation industry. To address these shortcomings, the development of interactive

simulations and virtual technology can enhance the effectiveness and efficiency of ATC training.

### The Latest Approach in Air Traffic Control Learning

The latest approach in Air Traffic Control (ATC) learning includes various innovative and effective strategies and methods to help students learn and master the skills required to become competent air traffic controllers. Some of the latest approaches that can be applied in ATC learning include:

1. Project-based approach: This method allows students to learn through real-world projects related to their work (Kokotsaki, Menzies, and Wiggins 2016). Students work in groups to complete tasks that require critical thinking and creativity. This approach helps students develop teamwork skills, hone their communication skills, and improve their ability to manage time and resources.

**Table 2. Air Traffic Control Learning Content Based on Project Approach**

No.	Learning Content Description	Description
1	Air Traffic Modeling and Simulation	Using air traffic simulation software to develop an understanding of the ATC system and improve decision-making skills in emergency situations.
2	Flight Route Mapping	Learning about flight regulations and different flight routes to understand how ATC manages air traffic in real-world situations.
3	Aviation Accident Analysis	Analyzing aviation accident cases to understand the causal factors and how they can be avoided in the future.
4	Safety Risk Assessment	Developing an understanding of how ATC assesses safety risks and honing skills in evaluating situations that may potentially pose risks.
5	Safety Risk Assessment	Developing an understanding of how ATC assesses safety risks and honing skills in evaluating situations that may potentially pose risks.
6	Air traffic data analysis	Collecting and analyzing air traffic data to understand trends and patterns in air traffic operations and how this information can be used to improve safety and efficiency.
7	Implementation of new technology	Investigating new technology implemented in the ATC system and gaining an understanding of how such technology affects air traffic operations and the ability of air traffic controllers.
8	Real-time air traffic monitoring	Using air traffic monitoring software to monitor air traffic in real-time and developing

No.	Learning Content Description	Description
		skills in making quick decisions in emergency situations.
9	Development of new ATC training programs	Developing new training programs for air traffic controllers and gaining an understanding of the process of developing training programs and how they can be adapted to address operational issues.
10	Simulation of new airport development	Learning the process of planning and building new airports and developing simulations of new airport development to understand operational challenges and identify solutions to overcome them

Project-based learning (PBL) is an effective approach in air traffic control (ATC) education that enhances collaboration, problem-solving, and creativity. By selecting relevant topics and designing engaging content, PBL allows students to integrate simulations and real-world tasks, such as emergency situation simulations and aviation accident analyses. This hands-on approach helps students develop practical skills like flight path planning and radio communication while increasing motivation and teamwork abilities. Feedback from ATC instructors indicates that PBL significantly improves understanding, critical thinking, and engagement. In summary, adopting PBL in ATC education deepens students' knowledge, refines their decision-making skills, and prepares them for success in the aviation industry, making it a highly recommended method for ATC learning programs.

1. Problem-based learning (Wood, 2003, Allen et al., 2011): This approach involves students in solving real-world problems related to their job as air traffic controllers. Students are given problems that they must solve using the knowledge and skills they have learned during their studies. This approach allows students to practice the skills and knowledge they have gained in real-world situations.

**Table 3. Problem-Based Learning Content in Air Traffic Control Education**

No.	Learning Content	Description
1	Emergency Situations in ATC	Students are asked to solve emergency situations in ATC such as aircraft experiencing technical problems or bad weather.
2	Aircraft Accidents	Students analyze aircraft accident cases and make recommendations to prevent similar accidents in the future.
3	Conflict Handling in ATC	Students learn how to handle conflicts that arise in ATC, either between aircraft or between air traffic controllers.
4	SOP Development in ATC	Students design new Standard Operating Procedures for air traffic controllers, which can improve the efficiency and safety of the ATC system.
5	Increasing Capacity at Airports	Students create plans to increase airport capacity by improving the ATC system and implementing new technologies.
6	New Technology Use in ATC	Students learn about new technologies used in the ATC system such as ADS-B (Automatic Dependent Surveillance-Broadcast) and analyze their impact on safety and efficiency.
7	National Flight Policy	Students learn about national flight policies and consider aspects such as regulation and safety.
8	Training Program Implementation	Students design and implement a training program for air traffic controllers that can enhance their decision-making skills and ability to handle emergency situations.
9	Implementation of Safety Management System	Students learn about safety management system and apply it to the ATC system to enhance flight safety.
10	Monitoring the Performance of the ATC System	Students learn how to monitor the performance of the ATC system and make improvements if necessary to enhance efficiency and safety.

Problem-based learning in air traffic control education offers several key benefits by making learning more contextual and relevant through real-world problems. It encourages critical and creative thinking, improves problem-solving abilities, and enhances decision-making skills in complex situations. Students also develop collaborative skills by working in teams, which are essential in the aviation industry. Additionally, this approach boosts motivation and interest by connecting learning to practical, industry-relevant scenarios, while preparing students to become competent professionals through exposure to policies, regulations, and the latest technologies in the dynamic aviation field.

2. Skill-based learning(Jamal Uddin et al. 2019): This method allows students to focus on developing specific skills that are required in their job as air traffic controllers, such as communication skills(Manning et al. 2002), decision-making(Ball et al., 2001,S. Fothergill & Neal, 2008,Grushka-Cockayne et al., 2008), and stress management. Students are taught these skills through simulations and exercises designed to strengthen their abilities to handle real-world situations(Fothergill et al. 2009).

**Table 4. Air Traffic Control Skill-Based Learning Content**

No.	Learning Content	Skills Learned
1.	Radar and Navigation System Use	Navigation and monitoring skills
2.	Radio Communication and ICAO Phraseology	Verbal communication skills
3.	Flight Path Mapping	Mapping and planning skills
4.	Aircraft Maintenance	Maintenance and repair skills
5.	Air Traffic Management (ATM)	Management and coordination skills

In skills-based learning content, the main focus is on developing practical skills that can be directly used by students in the workplace. The skills learned include navigation, communication, mapping, maintenance, and air traffic management. Students learn through simulation and direct practice to develop skills and prepare for working in the air traffic industry. Skills-based learning in air traffic control education offers several advantages by focusing on practical, work-relevant skills. Through simulations and hands-on practice, students acquire essential skills directly applicable to their future careers, improving their practical abilities and memory retention. This approach also fosters active, interactive learning, engaging students in meaningful activities that prepare them for real-world situations. It enhances career development by equipping students with the necessary skills to succeed and advance in the dynamic air traffic industry.

3. Game-based learning(Tobias, Fletcher, and Wind 2014): This approach uses game elements in ATC learning. Students learn through games designed to develop their skills in decision-making, time management, and technical skills required in the job as an air traffic controller.

**Table 5. Skills-Based Air Traffic Learning Content**

No.	Learning Content
1	Flight simulation games to gain experience in navigating aircraft in the air and dealing with emergency situations.
2	Flight simulation games to gain experience in navigating planes in the air and handling emergency situations.
3	Air traffic control simulation games to gain experience in guiding planes towards the runway and avoiding collisions.
4	Memory games to train recognition of ATC codes and air traffic terms.

5	Crossword puzzle games to enhance understanding of concepts and basic principles in air traffic control.
6	Game simulation of weather to gain understanding of how weather affects flights and how to handle bad weather situations.
7	Interactive quiz game to gain understanding of rules and regulations in air traffic control.

Game-based learning in air traffic control education significantly boosts motivation and engagement through fun, interactive experiences that provide realistic scenarios. This approach facilitates active, self-directed learning, allowing for easy repetition and evaluation to enhance skills. By working together to tackle challenges, students also develop crucial teamwork abilities needed in the air traffic industry. Overall, game-based learning makes the educational process more enjoyable while helping students gain relevant experiences and effectively apply their knowledge and skills in real-world situations, ultimately enhancing the effectiveness of ATC training.

### **Innovative Methods in Air Traffic Control Learning**

Innovative methods in Air Traffic Control (ATC) learning are approaches that utilize technology, creativity, and different learning strategies to enhance the quality and effectiveness of ATC learning. These innovative methods aim to improve the learning process and ensure that students can gain a good understanding of the basic concepts and principles of ATC, as well as develop the skills and abilities required to become a successful air traffic controller.

Some examples of innovative methods in ATC learning are as follows:

1. **Simulation:** The use of simulation in ATC learning can provide a realistic and interactive experience for students, allowing them to gain a better understanding of the situations and tasks involved in ATC.

The simulation method in air traffic control learning is an innovative approach that can be used to help students understand the tasks and responsibilities involved in their duties. Simulation allows students to experience real-life situations and gain experiences that are similar to those they will face in the real world (Manske and Schier 2015). In simulations, students will be given different air traffic scenarios, and they must make the right and effective decisions to handle those situations.

**Table 6. Simulations in Air Traffic Control Learning**

<b>No.</b>	<b>Simulation Type</b>	<b>Description</b>
1	Radar Simulation	Students can learn how to use radar to monitor aircraft in the air.
2	Communication Simulation	Students can practice communicating with pilots and other relevant parties.
3	Crisis Scenario Simulation	Students can learn how to handle emergency situations such as plane crashes.
4	Flight Simulation	Students can experience flight situations such as take-off, landing, and emergencies.

No.	Simulation Type	Description
5	Bad Weather Scenario Simulation	Students can learn how to handle bad weather situations such as storms or fog.
6	Air Traffic Control Tower Simulation	Students can learn how to operate the ATC tower and oversee air traffic.
7	Decision-Making Simulation in Limited Situations	Students can practice effective decision-making in critical situations.

In every type of simulation, students will be presented with different scenarios where they must make the right decisions and coordinate with their team in handling the situation. Each simulation is equipped with technology that allows students to experience a closer experience to the real world, such as the use of Air Traffic Control (ATC) Simulator Laboratories, Flight Simulator laboratories, and sound simulations to add a more engaging and realistic experience.



**Figure 2. Innovative Learning Simulation Using Atc Simulator**

Simulation methods in air traffic control education provide valuable opportunities for students to develop key skills. These include decision-making, where students learn to make quick, accurate choices in critical situations, and team coordination, fostering the ability to work effectively with others. Simulations also teach stress management, helping students handle pressure in high-stakes scenarios, while improving technical skills through hands-on experience with navigation tools, radar, and other essential equipment. Simulations emphasize the importance of maintaining a professional attitude and ethics, preparing students for real-world responsibilities in the air traffic control industry. Furthermore, simulation methods can also help improve students' motivation to learn and make learning more enjoyable. Simulations can display attractive graphics and animations that make students more interested and engaged in learning.

**Table 7. Implementation Flow of Simulation Activities in Air Traffic Education**

Stage	Description
Preparation	a. Determining learning objectives b. Choosing the type of simulation to be conducted c. Preparing necessary facilities and equipment
Briefing	a. Creating a presentation about the simulation and the scenario to be conducted b. Explaining rules and regulations that must be followed by the students
Simulation Execution	a. Students conduct the simulation according to the predetermined scenario b. Teacher or instructor gives directions and feedback to the students c. Students can take notes on the results or conclusions from the simulation
Debriefing	a. Teacher or instructor gives feedback and evaluation to the students b. Students are given the opportunity to provide input and share their experience during the simulation
Reflection	a. Students conduct self-reflection and discuss their experience during the simulation b. Teacher or instructor gives suggestions and recommendations for further improvement

In each stage, it is important to ensure that students understand the learning objectives and rules that must be followed during the simulation. Additionally, the implementation of the simulation should be done well and meet students' needs to maximize learning outcomes. After the simulation is completed, debriefing and self-reflection should be conducted so that students can understand what they have learned and how they can improve their skills further. However, simulation methods also have weaknesses, such as the high cost of development and use. Moreover, simulations may not be able to replicate all situations that may occur in the real world, so students still need to learn through direct experience in real-life situations.

2. Virtual Reality (VR) and Augmented Reality (AR): VR and AR technologies can be used to create more realistic and interactive simulations, so that students can experience learning as if in the real world. Virtual Reality (VR) and Augmented Reality (AR) are increasingly popular technologies in air traffic education because they can provide students with more interactive and realistic learning experiences. VR is a technology that allows users to experience and interact with virtual environments created by computers. In the context of air traffic education, students can use VR to experience situations that may be difficult or even dangerous if done in the real world, such as landing an aircraft on different runways or dealing with bad weather.



**Figure 3. AR for Tower Simulator**

Augmented Reality (AR) combines virtual objects with the real world, allowing students in air traffic education to view additional information and visualizations, such as 3D aircraft models and directional indicators for landings. Both AR and Virtual Reality (VR) enhance student understanding of complex concepts by providing realistic simulations and instant feedback, which strengthen comprehension of various aviation scenarios. VR improves engagement, visualization skills, and practical abilities through immersive real-world simulations, but it faces challenges such as high costs, limited accessibility, and potential health risks. AR, while easily accessible via smartphones and effective in boosting motivation and clarifying difficult concepts, has limitations in features and requires suitable devices. Despite their challenges, when integrated effectively with other methods, VR and AR can provide valuable and immersive learning experiences in air traffic education.

*Analysis of comparison between conventional and innovative methods of air traffic learning*

Comparison of air traffic control (ATC) learning methods using conventional and innovative models was based on student performance during ATC practicum using the conventional model in the Manual ATC Laboratory and the innovative model in the ATC Simulator Laboratory. Four different values were taken into consideration: Traffic Information, Communication Failure, Urgency Situation, and Emergency Situation.

Normality testing was not performed in this study and a Two Sample Mean Test was used directly.

**A. T-Test**

**A. Traffic Info**

**Table.8 "Ttest Trafficinfo, By(Group)" Two-Sample T Test with Equal Variances**

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interv al]
ATC manual	48	73.16667	.4729691	3.276826	72.21518	74.11816

ATC Simulator	48	77.3125	.575933	3.990181	76.15387	78.47113
combined	96	75.23958	.42734	4.18706	74.39121	76.08796
diff		-4.145833	.7452507		-5.625546	-2.666121

diff = mean(AFIS Man) - mean(ATC Simu)      t = -5.5630

Ho: diff = 0      degrees of freedom = 94

Ha: diff < 0      Ha: diff != 0      Ha: diff > 0 Pr(T < t) = 0.0000  
 Pr(|T| > |t|) = 0.0000      Pr(T > t) = 1.0000

From the data above, it can be concluded that in actuality, the value of "Traffic Info" with the ATC Simulator is greater than the ATC manual. Statistically, the value of Prob(T<t) is 0.000 which is less than alpha=0.05. Therefore, this difference is significant.

**B. Communication Failure**

**Table.9 "T test Comfail, By (Group" Two-Sample T Test with Equal Variances**

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
ATC manual	48	73.3125	.4062415	2.814524	72.49525	74.12975
ATC Simulator	48	76.52083	.5317821	3.684294	75.45103	77.59064
combined	96	74.91667	.3713024	3.638006	74.17954	75.6538
diff		-3.208333	.6691968		-4.537039	-1.879627

diff = mean(AFIS Man) - mean(ATC Simu)      t = -4.7943

Ho: diff = 0      degrees of freedom = 94

Ha: diff < 0      Ha: diff != 0      Ha: diff > 0 Pr(T < t) = 0.0000  
 Pr(|T| > |t|) = 0.0000      Pr(T > t) = 1.0000

From the data above, it can be concluded that in actuality, the "Communication Failure" value with the ATC Simulator is greater than with the ATC manual. Statistically, the value of Prob(T<t) = 0.000 is less than alpha=0.05. Thus, this difference is significant.

**C. Urgency Procedure**

**Table.10 "T Test Urgency, By(Group)" Two-Sample T Test With Equal Variances**

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.]	Interval]
ATC manual	48	73.04167	.3718346	2.576145	72.29363	73.7897
ATC Simulator	48	75.97917	.3966723	2.748226	75.18116	76.77717
combined	96	74.51042	.3095677	3.033132	73.89585	75.12499
diff		-2.9375	.5437002		-4.017029	-1.857971

diff = mean(AFIS Man) - mean(ATC Simu)      t = -5.4028  
 Ho: diff = 0      degrees of freedom = 94

Ha: diff < 0      Ha: diff != 0      Ha: diff > 0 Pr(T < t) = 0.0000  
 Pr(|T| > |t|) = 0.0000      Pr(T > t) = 1.0000

Based on the data above, it can be concluded that the actual value of "Urgency Procedure" with ATC Simulator is greater than ATC manual. Statistically, the value of Prob(T<t) is 0.000 which is less than alpha=0.05. Therefore, this difference is significant.

**D. Emergency Procedure**

**Table.11 "T test Emg , By (Group)" Two-Sample T Test with Equal Variances**

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.]	Interval]
ATC manual	48	72.77083	.4213281	2.919047	71.92323	73.61844
ATC Simulator	48	77.29167	.6385644	4.424104	76.00704	78.57629
combined	96	75.03125	.4456055	4.366025	74.14661	75.91589
diff		-4.520833	.7650372		-6.039833	-3.001834

diff = mean(AFIS Man) - mean(ATC Simu)      t = -5.9093  
 Ho: diff = 0      degrees of freedom = 94

Ha: diff < 0      Ha: diff != 0      Ha: diff > 0 Pr(T < t) = 0.0000  
 Pr(|T| > |t|) = 0.0000      Pr(T > t) = 1.0000

From the data above, it can be concluded that in actuality, the value of "Emergency Procedure" with the ATC Simulator is greater than the ATC manual. Statistically, the value of Prob(T<t) is 0.000 and less than alpha=0.05. Thus, this difference is significant.

**E. Mean**

**Table.12“T Test Mean, By(Group)” Two-Sample T Test with Equal Variances**

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
ATC manual	48	73.07292	.253626	1.757172	72.56269	73.58315
ATC Simulator	48	76.77604	.2985113	2.068147	76.17551	77.37657
combined	96	74.92448	.272107	2.666093	74.38428	75.46468
diff		-3.703125	.391708		-4.48087	-2.92538

diff = mean(AFIS Man) - mean(ATC Simu)      t = -9.4538  
 Ho: diff = 0    degrees of freedom = 94

Ha: diff < 0                      Ha: diff != 0                      Ha: diff > 0  
 Pr(T < t) = 0.0000      Pr(|T| > |t|) = 0.0000      Pr(T > t) = 1.0000

From the data above, it can be concluded that actually, the "Average" value with ATC Simulator is greater than ATC manual. Statistically, the value of Prob(T<t)= 0.000 and is less than alpha=0.05. Thus, this difference is significant. A comparative analysis of konvensional and innovative air traffic learning methods was also conducted descriptively, as used in air traffic learning, indicating significant differences in approach, methods, and learning outcomes.

Conventional and innovative learning methods differ significantly, with conventional approaches following a linear, teacher-centered model using basic tools like textbooks, while innovative methods are holistic and interactive, integrating technologies such as VR, AR, and simulations. Innovative methods are more flexible, catering to diverse learning styles and employing various assessment tools, including simulations and interactive games, which enhance student engagement and effectiveness. In air traffic control training, innovative methods have been shown to improve understanding and skills, as supported by interviews with air traffic personnel and instructors. While VR, AR, and simulations are valuable for developing operational skills, conventional methods still play a crucial role in teaching theory and foundational concepts in air traffic control.

**Several Factors that can Affect the Effectiveness of Air Traffic Learning**

Several factors can influence the effectiveness of air traffic learning. First, the quality of teaching methods plays a critical role; poor methods can hinder students' understanding and skill mastery. Psychological factors, such as student motivation, interest, and self-confidence, also impact learning success, with unmotivated students struggling to engage. The learning environment, including classroom atmosphere and resources, affects focus and performance, while teacher skills, such as clear communication and providing feedback, are equally important. The appropriate use of technology enhances learning, but improper use can create confusion. Lastly, social factors, like student-teacher interactions and cultural diversity, contribute to a more effective and inclusive learning experience.

**DISCUSSION**

Effective Air Traffic Control (ATC) learning is essential for ensuring aviation safety, necessitating the adoption of innovative approaches such as problem-based, project-based, and skill-based methods. These strategies focus on real-life scenarios to enhance student engagement and understanding of complex ATC concepts. Additionally, incorporating technologies like simulations, virtual reality (VR), and augmented reality (AR) allows students to experience realistic flight situations, thereby improving their practical skills. To optimize ATC learning, it is crucial to enhance teaching quality, foster social interaction, and involve industry professionals in the educational process. Regular evaluations and an updated curriculum that reflects emerging technologies can further bolster learning outcomes. Ultimately, selecting the appropriate learning methods tailored to students' needs will enhance their preparation for the aviation industry.

**Table.13 Advantages and Disadvantages of Conventional and Innovative Methods in Air Traffic Control Learning**

	<b>Conventional Method</b>	<b>Innovative Method</b>
Advantages	- Proven to be effective widely.	- More interactive and engaging for students.
	- Has many learning resources, such as textbooks and direct instruction from the teacher.	- Allows students to learn independently with technology such as videos and simulations.
	- Easier to arrange and implement by the teacher.	- Enables students to learn at their own pace.
Disadvantages	- Less flexible in accommodating different learning styles of students.	- Requires access and adequate technology skills.

	- May feel boring for students who are not engaged.	- May require additional cost for technology and equipment.
	- Not always possible for students to learn independently.	- May require specialized training for teachers to use the technology.

## CONCLUSION

Based on the above discussion, it can be concluded that Air Traffic Control learning can be more effectively conducted through the use of modern approaches and innovative methods. Modern approaches that can be used include problem-based, project-based, and skill-based learning. Meanwhile, innovative methods that can be used include simulation, games, virtual reality (VR), and augmented reality (AR). There are factors that influence the effectiveness of Air Traffic Control learning, such as teacher ability, facilities, curriculum, and student motivation. Therefore, recommendations for more effective Air Traffic Control learning include improving the curriculum and updating facilities, as well as providing training and support to teachers to use modern approaches and innovative methods.

Research also shows that the use of modern approaches and innovative methods in Air Traffic Control learning can improve student understanding and skills. A comparative study shows that students who learn with innovative methods have better scores than those who learn with konvensional methods. Therefore, educators can consider using modern approaches and innovative methods in Air Traffic Control learning to improve learning effectiveness and student outcomes.

## RECOMMENDATION

For further research on more effective Air Traffic Control learning, several recommendations can be made. First, research can focus on the application of more advanced technology in ATC learning, such as the use of simulations and augmented reality. Second, research can focus on the development of more specific learning content tailored to individual student needs, such as adjusting learning content based on student ability and experience levels. Third, research can focus on the development of more creative and interactive learning approaches, such as problem-based or project-based learning. In future research, evaluations can also be conducted on the effectiveness of training programs that have been implemented in specific educational institutions to produce graduates with the appropriate skills for the aviation industry. Evaluating these training programs can help improve their effectiveness and ensure that graduates produced are suitable for the aviation industry's needs.

## ACKNOWLEDGMENT

The author would like to express sincere gratitude to Surabaya Aviation Polytechnic for the financial support provided for this research in the year 2024. This study would not have been possible without the institutions generous funding and encouragement. The resources and support from the Surabaya Aviation Polytechnic were crucial in facilitating the successful completion of this research on effective Air Traffic Control (ATC) learning through new approaches and innovative methods.

## REFERENCES

- Allen, D. E., Donham, R. S., & Bernhardt, S. A. (2011). Problem-based learning. *New Directions for Teaching and Learning*, 2011(128), 21–29. <https://doi.org/10.1002/tl.465>
- Ball, M. O., Chen, C. Y., Hoffman, R., & Vossen, T. (2001). Collaborative decision making in air traffic management: Current and future research directions. *Proceedings*, 17–30.
- Bauer, M., & Langr, D. (2017). Workload - New possibilities for the ATC simulation environment. *ICMT 2017 - 6th International Conference on Military Technologies*, 447–451. <https://doi.org/10.1109/MILTECHS.2017.7988801>
- Di Stasi, L. L., Marchitto, M., Antolí, A., Baccino, T., & Cañas, J. J. (2010). Approximation of on-line mental workload index in ATC simulated multitasks. *Journal of Air Transport Management*, 16(6), 330–333. <https://doi.org/10.1016/j.jairtraman.2010.02.004>
- Fothergill, S., & Neal, A. (2008). The effect of workload on conflict decision making strategies in air traffic control. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 52(1), 39–43. <https://doi.org/10.1177/154193120805200110>
- Fothergill, S., Loft, S., & Neal, A. (2009). ATC-LabAdvanced: An air traffic control simulator with realism and control. *Behavior Research Methods*, 41(1), 118–127. <https://doi.org/10.3758/BRM.41.1.118>
- Gerring, J. (2017). Qualitative methods. *Annual Review of Political Science*, 20(1), 15–36. <https://doi.org/10.1146/annurev-polisci-092415-024158>
- Gorbunov, A. L., & Nechaev, E. E. (2022). Augmented reality technologies in air transport control systems. *Proceedings of the 2022 Systems of Signals Generating and Processing in the Field of on Board Communications*, 1–5. IEEE.
- Gordon, R., Kirwan, B., & Perrin, E. (2007). Measuring safety culture in a research and development centre: A comparison of two methods in the air traffic management domain. *Safety Science*, 45(6), 669–695. <https://doi.org/10.1016/j.ssci.2007.04.004>
- Grishin, I. Y., & Timirgaleeva, R. R. (2017). Air navigation: Optimisation control of means cueing of the air-traffic control system. *Proceedings of the 2017 21st Conference of Open Innovations Association (FRUCT)*, 134–140. IEEE.
- Gretton, A., Borgwardt, K. M., Rasch, M. J., Smola, A., Schölkopf, B., & Smola, A. (2012). A kernel two-sample test. *Journal of Machine Learning Research*, 13, 723–773.
- Grushka-Cockayne, Y., De Reyck, B., & Degraeve, Z. (2008). An integrated decision-making approach for improving European air traffic management. *Management Science*, 54(8), 1395–1409. <https://doi.org/10.1287/mnsc.1080.0878>
- Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn?. *Educational Psychology Review*, 16(3), 235–266.

- Jamal Uddin, M., Panda, B. N., Agarwal, P. C., Nunaki, J. H., Damopolii, I., Nusantari, E., & Kandowangko, N. Y. (2019). The contribution of metacognitive in the inquiry-based learning to students' thinking skill based on SOLO taxonomy. *Journal of Physics: Conference Series*, 1321(3), 032044. <https://doi.org/10.1088/1742-6596/1321/3/032044>
- Kendall-Taylor, N., Erard, M., & Haydon, A. (2013). The use of metaphor as a science communication tool: Air traffic control for your brain. *Journal of Applied Communication Research*, 41(4), 412-433. <https://doi.org/10.1080/00909882.2013.836678>
- Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools*, 19(3), 267-277. <https://doi.org/10.1177/1365480216659733>
- Koskela, I., & Palukka, H. (2011). Trainer interventions as instructional strategies in air traffic control training. *Journal of Workplace Learning*, 23(5), 293-314. <https://doi.org/10.1108/13665621111141902/full/xml>
- Lin, C. J., & Wang, T. I. (2012). Applying augmented reality in high school chemistry education. *Proceedings of the 11th International Conference on Computer Supported Collaborative Learning*, 32(3), 369-374.
- Lin, Y. (2021). Spoken instruction understanding in air traffic control: Challenge, technique, and application. *Aerospace*, 8(3), 65. <https://doi.org/10.3390/aerospace8030065>
- Loft, S., Hill, A., Neal, A., Humphreys, M., & Yeo, G. (2004). ATC-Lab: An air traffic control simulator for the laboratory. *Behavior Research Methods, Instruments, & Computers*, 36(2), 331-338. <https://doi.org/10.3758/BF03195579>
- Manning, C., Fox, C., Pfleiderer, E., Mills, S., & Mogilka, H. (2002). The relationship between air traffic control communication events and measures of controller taskload and workload. *Air Traffic Control Quarterly*, 10(2), 69-83. <https://doi.org/10.2514/atcq.10.2.69>
- Manske, P. G., & Schier, S. L. (2015). Visual scanning in an air traffic control tower - A simulation study. *Procedia Manufacturing*, 3, 3274-3279. <https://doi.org/10.1016/j.promfg.2015.07.397>
- Masotti, N., Bagassi, S., & De Crescenzo, F. (2016). Augmented reality for the control tower: The RETINA concept. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 9768, 444-452. [https://doi.org/10.1007/978-3-319-40621-3\\_32/cover](https://doi.org/10.1007/978-3-319-40621-3_32/cover)
- Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, 38(1), 43-52.
- Papastergiou, M. (2009). Digital game-based learning in high school computer science education: Impact on educational effectiveness and student motivation. *Computers & Education*, 52(1), 1-12.
- Reisman, R., & Brown, D. (2006). Design of augmented reality tools for air traffic control towers. *Proceedings of the 6th AIAA Aviation Technology, Integration and Operations Conference (ATIO)*. American Institute of Aeronautics and Astronautics.
- Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, 55(1), 68-78.
- Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. *Personnel Psychology*, 64(2), 489-528.
- Soldatov, S. K., Zasyad'ko, K. I., Bogomolov, A. V., Vonarshenko, A. P., & Solomka, A. V. (2018). Professionally important skills of air traffic controllers. *Human Physiology*, 44(7), 775-778. <https://doi.org/10.1134/S0362119718070150/metrics>