Mastering automation: New airline pilots' perspective

Kassandra Kim Yoke Soo, Timothy J. Mavin, and Yoriko Kikkawa

Griffith Institute for Educational Research, Griffith University, Mt Gravatt, Queensland, Australia

Corresponding author: Timothy J. Mavin
Postal address: Griffith Institute for Educational Research, Mt Gravatt campus, Griffith University, 176 Messines Ridge Road, Mt Gravatt QLD 4122, Australia
Email: t.mavin@griffith.edu.au
Facsimile: (07) 373 56992
Mastering automation: New airline pilots' perspective

Aircraft accidents over the last decade have raised questions about the most effective way to transition pilots onto new aircraft automation systems. This debate can range from the details contained within aircraft flight manuals to computer-based versus simulator-based training. While some questions are still under consideration, most fall short in the understanding of how pilots “actually” learn. The researchers conducted a longitudinal study focusing on pilot learning; through interviews, observations, and field documentation, 10 pilot trainees from two regional airlines were followed for 5 months throughout their initial airline training. Using joint cognitive systems theory, and concepts from curriculum theory to understand the utility of training programs, the study revealed gaps between the airlines’ intended learning outcomes and the trainees’ actual experiences. The findings demonstrate that automation, as opposed to other aircraft systems, may require different approaches to learning. Recommendations for possible modifications to current pilot training are discussed.

Keywords: joint cognitive systems; automation; learning; airline pilot

Introduction

The U.S. Federal Aviation Administration (FAA, 1996) has reported major changes in the field of aviation because of technological advancements since the 1970s. For example, the invention of the transistor in 1947 and subsequent miniaturization of computer components has led many aircraft manufacturers to include automated aircraft systems and new flight deck designs. These changes meant that flight engineers, radio operators, and navigators were no longer needed on board (Billings, 1997; Koonce & Debons, 2009). Consequently, as pilots’ work altered, new problems emerged.

During the introduction of new cockpit technologies in the 1960s when pilots were transferring from an analogue flight deck to glass cockpits, human factors issues associated
with automation in the flight deck were being identified (Billings, 1997). These issues were mostly attributed to breakdowns in communication and coordination with flight deck automation (FAA, 1996). Pilots transitioning to glass for the first time, for example, had difficulty understanding and properly utilising the auto flight modes, leading to mode errors. More specifically, the pilots were selecting “an inappropriate mode, not understanding the implications of choice of mode, not realizing what mode was engaged, and failing to recognize that a change in mode had been made not by pilot selection, but by the FMS [flight management system; emphasis added]” (Wiener et al., 1999, pp. I-10).

A more recent report by the Flight Deck Automation Working Group (FAA, 2013) stated that there have been significant changes to the use of aircraft automation since its last review in the late 1990s. These changes include increased aircraft onboard capabilities for flight path management using (a) more capable flight management computer (FMC; sometimes referred to as flight management system (FMS); (b) more advanced navigation systems such as area navigation (RNAV), required navigation performance (RNP), and global positioning system (GPS); and (c) more advanced digital data presentation contained within the primary flight display (PFD), navigation display (ND), mode control panel (MCP), multi-function display (MFD), and control display unit (CDU) (see Figure 1). Pilots were required to adapt to such changes; however, this report highlighted that “current training methods, training devices, the time allotted for training, and content may not provide the flight crews with the knowledge, skills, and judgment to successfully manage flight path management systems” (FAA, 2013, p. 4).
Historically, pilot training focused on psychomotor and procedural competencies (Mavin & Murray, 2010). As automation improved, training started to include aspects of the human pilot and automated systems interface (Fanjoy & Young, 2004, 2005; Wood & Huddlestone, 2006; Young & Fanjoy, 2003). In fact, automation has become so advanced that many researchers have termed it the third agent of control in the flight deck (Christoffersen & Woods, 2002; Klein et al., 2005; Klein et al., 2004), that can sometimes completely replace human decision-making (Parasuraman & Manzey, 2010; Parasuraman et al., 2008). However, Strauch (2017) reported that pilots today still experience the same automation issues identified in the past, such as systems and performance awareness (Mouloua & Koonce, 1997) and automation surprise (Sarter et al., 1997). This leads to the question of the effectiveness of current pilot training; more specifically, that the current training does not reflect how pilots work and how they learn to work with complex automation systems.
Joint Cognitive Systems

The theoretical framework of joint cognitive systems is one method developed in the field of cognitive systems engineering and has been used to understand complex performances of pilots (Hollnagel & Woods, 2005; Soo et al., 2016). The fundamental goal of this framework was to shift the focus of measurement of human capabilities from traditional information processing theories to the joint interactions between two agents (human or automated) by examining how these agents interact with each other to perform work as a shared responsibility. Hollnagel and Woods (2005, p. 47) defined cognition in the framework as the “ability for the system to modify its pattern of behaviour on the basis of past experience in order to achieve specific anti-entropic ends”—in other words, the focus is on the system’s ability to maintain equilibrium and functioning during normal and non-normal situations.

Portraying the aircraft flight deck as a joint cognitive system is not new, as many researchers have investigated pilot work through this perspective (Harris, 2013; Henriqson et al., 2011; Hutchins, 1995; Roth et al., 2015; Soo et al., 2016). What is lacking, however, is an understanding of how pilots are expected to become a component of such a system. The current theory of joint cognitive systems emphasizes a pragmatic delineation of the boundaries of the joint cognitive system under analysis with two conditions: if an element (e.g., human or automation) can cause a significant change to the joint cognitive system and, most importantly, if the element can be controlled by the joint cognitive system (Hollnagel & Woods, 2005). However, this kind of pragmatic boundary offers limited insights when investigating the process of cognitive development (Soo et al., 2016) or, as in this study, learning of new knowledge and skills. As such, the concepts of functional system and functional units outlined by Luria (1973) were used to understand the constellations or components of a system. Viewing the joint cognitive system as a functional system promotes
the idea that components within the system (i.e., functional units) are always changing due to different reasons (Travieso, 2007). As human-machine interaction literature proposes a relationship between pilots (human) and automation (machine) as a “team” (Degani et al., 2017, p. 212), aircraft automation is understood to be part of the cognitive system of the flight deck. If a resilient joint cognitive system is the aim of safe aircraft operations, then pilot training should be structured in a manner that will lead to this goal.

In this paper, the end goal of pilot training is for the pilot to become a useful component within the framework of joint cognitive systems. With this prospect in mind, the general framework of aviation joint cognitive systems (human–human–automation) becomes the basis for determining the state of learning of the pilot: specifically, when do pilots start to view automation and themselves as part of the joint cognitive system? Therefore, focusing only on automation aspects of the learning and training process, this paper explores when pilots truly start viewing automation as part of the joint cognitive system, and how current training practices scaffold the development of these links (i.e., automation as a crew member) during training. The empirical research of pilots’ experiences as they complete a training program that is meant to prepare them for the realities of pilot work is now presented.

Curriculum Theory

To explore how new pilots entering an airline experience a training program, Billett’s (2006) curriculum theory was used as the theoretical lens to understand the different experiences during training. The term “curriculum” is usually used in the context of academic and vocational education, although it is slowly entering the domain of workplace learning as it provides useful concepts for understanding workplace practices (Billett, 1996, 2006, 2009). Aviation training programs are also found to be developed in ways that are similar/identical to how other educational curricula are developed.
Billett (2006) proposes three elements of curriculum: (a) intended, (b) enacted, and (c) experienced. His conceptualization of curriculum includes not only what needs to be learned and assessed but also how it is implemented by instructors and experienced by learners. Hence, the development of a training curriculum is more than just having plans and a list of competencies (e.g., knowledge, technical skills, non-technical skills, and abilities) to be taught and learned. Instead, it is a dynamic and complex process between the organisers who plan, instructors who enact, and learners who learn (Billett, 2006). The holistic nature of this approach made it well suited to exploring the different aspects of pilot training systematically. Therefore, in the context of this study, a curriculum is conceptualized as a training program for pilots encompassing learning experiences in training settings, how they are organized and sequenced by training managers, and enacted by instructors.

**Methods**

This study was part of a larger longitudinal project that focused on the broad topic of learning and development of pilots. The study employed a case study approach as it aims to yield a rich and thick description of pilot learning using multiple methods (Stake, 2003). This paper focuses particularly on the learning of automation by First Officers during their initial airline training which included a type rating.

A total of 10 pilot cases were involved in this study. The study sites were two regional airlines operating large, single-aisle turboprop aircraft. Airline A operated the ATR72-500 and the newer ATR72-600. Airline B operated three variants of the Dash 8, though pilots in this study transitioned onto the newer DHC8-400. In total, six pilots from Airline A and four from Airline B (nine males and one female) were involved in the study and for ease and anonymity will be referred to throughout as “he” and labelled P1 through P10. Pilots from Airline A were already working within general aviation or small airlines, while Airline B
pilots were university-trained pilot cadets. These pilots had previously conducted a multicrew coordination course on a Boeing 737 and the ground theory DHC8-400 prior to commencing the type-rating training. The average age and total flight hours of pilots were 28.2 years ($SD = 6.96$) and 2211.7 hours ($SD = 1,861.30$) respectively.

Data was collected daily throughout the training program through interviews, observations, and field documentation. For pilots in Airline A, this included the start of ground training until pilots were type rated, while pilots in Airline B were followed only during the type rating training (as ground school was conducted in the university). Reflective semi-structured interviews were conducted with each pilot several times throughout the training to the end of line training. These interviews used open-ended questions to facilitate the pilot’s reflection on the learning experience (i.e., positive, neutral, and negative). All interviews, classroom sessions, and briefing and debriefing sessions were audio- and video-recorded and later transcribed for analysis. For consistency in presenting findings, aircraft components discussed by pilots were relabelled into their generic names. For example, during discussions about specific topics, pilots may use aircraft type specific names, like GNSS/computer, or even refer to a system as “it”. In this case, the generic label CDU would be used.

To examine learning processes, the overarching structure of four training phases were identified through document review (intended curriculum) and modified through observation fieldnotes (enacted curriculum). Data collected were segmented and analysed systematically according to these phases. During the first phase of ground school (2 weeks), pilots were initially introduced to automation via computer-based training and instructor-led discussions. During the second phase of the part task trainer (1 week), pilots were trained in pairs by an instructor to develop an understanding of the flight management computer and standard
operating procedures (SOPs). The third phase was full flight simulator (5 weeks) where pilots were again paired to complete approximately 12 sessions of 4-hour full-flight simulator training exercises. Finally, during the fourth phase of line training and final checked to line assessment (6 weeks), pilots conducted on-the-job training on their respective aircraft with a training captain and assessed at the of the entire training phase. See Figure 2 for the main training tools used by participating airlines.

*Figure 2.* Flat panel trainer (left) with full flight simulator (right).

As understanding the pilots’ learning was the aim of the study, interview data (i.e., pilots’ perspectives or experienced curriculum) was the primary source of data. A total of 49 hours of interview data was transcribed and analysed using thematic analysis (Braun & Clarke, 2006) in combination with narrative inquiry techniques (Sonday et al., 2020). This inductive approach was used to identify key learning processes, or critical events, that the pilots experienced at different phases of training. More specifically, these pilots talked about what they found easy or what training methods or processes they liked or helped them learn (i.e., positive experiences); they highlighted the difficulties that they had or what training methods or processes they disliked (i.e., negative experiences); and they simply described what they did (i.e., neutral experiences). Furthermore, their talk around their learning
experiences was also used to confirm the enacted curriculum that was examined from observation data (e.g., delivery of the program).

The coding process of interview data started with a single case analysis by the first author to develop a detailed case narrative for each pilot, which provided a holistic overview of their individual experiences (Sonday et al., 2020). This process highlighted critical events or aspects that influenced pilots’ learning and development during the training program which was used to generate the initial codes. Cross-case analysis was then conducted by using these initial codes to code all interview texts identified previously. Cross-checking activities were conducted independently by each of the other authors, which led to modifications of coding structures. This reviewing process occurred until consensus was obtained. The final coding involved four key areas of pilot learning: aircraft type-specific knowledge, procedures, automation, and social skills. Accordingly, text segments reflecting positive, negative, and neutral experiences were grouped under each of these four areas and were further analysed to identify subthemes in terms of how pilots develop their competence around these key areas. The results of the analysis were then cross-checked with observation data.

For this paper, further analysis was conducted to examine key learning processes particularly of pilots mastering automation by grouping text segments reflecting positive and negative experiences relating to automation into a tabular summary according to each training phase and for each pilot. Text segments grouped were then re-examined to explore what aspects of learning and development these pilots discussed most in terms of automation at each of the training phases. Through this exploratory process, it became apparent that pilots talked more about automation at the later stage of the training program. The researchers then double-checked the coding results of some texts for automation during the earlier stage of the
program, deciding to include some of the interview texts indirectly reflecting pilots’ experience of learning automation (e.g., learning content of aircraft system). A total of nine subthemes were identified to represent how the pilots shifted their perceptions of their mastery of automation throughout training: (1) one of the many systems, (2) adapting past experience, (3) programming FMC with CDU, (4) understanding automation functionality, (5) maintaining aircraft awareness, (6) timing procedures to align with automation, (7) applying theory into practice, and (8) practice automation use. Table 1 clarified the meaning of these subthemes, which will be progressively reported according to the training phases in the following section.

<table>
<thead>
<tr>
<th>Subthemes</th>
<th>Quote example</th>
</tr>
</thead>
<tbody>
<tr>
<td>One of the many systems</td>
<td>It’s all straight forward and auto pilot stuff. It’s quite mundane. (P2)</td>
</tr>
<tr>
<td>Adapting past experience</td>
<td>I’ve used [Boeing 737] before on the simulator…so it’s just that positive transfer of the knowledge. (P1)</td>
</tr>
<tr>
<td>Programming FMC with CDU</td>
<td>Trickiest thing was to remember was the first step to get you into the part of the unit that you need to be in. (P2)</td>
</tr>
<tr>
<td>Understanding automation functionality</td>
<td>I’m not understanding what mode I need to be in. (P2)</td>
</tr>
<tr>
<td>Maintaining aircraft awareness</td>
<td>You can’t feel the trim in a certain sense. You’re kind of just touching a button until you see it line up…. I feel like the autopilot made it more difficult and increased my workload. (P8)</td>
</tr>
<tr>
<td>Timing procedures to align with automation</td>
<td>If you don’t get it done in time, and you do level off, that’s going to stuff your flow. (P4)</td>
</tr>
<tr>
<td>Applying theory into practice (breaks in training)</td>
<td>We did [FMC] when we were at [university]… I was really scratching my head thinking, “How do I do that again?” because all the sims up to now had no FMC. (P7)</td>
</tr>
<tr>
<td>Practicing automation use</td>
<td>The more you [use automation], the more you get used to it, the more confident you become with it, the more reassured that the aircraft is going to do what you’re telling the aircraft to do. [P2]</td>
</tr>
</tbody>
</table>

**Findings**

The tabular summary of automation coding indicated every pilot discussed automation as a key topic in terms of their learning (see Table 2). The overall reflection of researchers’ analysis underlined that automation became a major theme of the study at the later stages of training when pilots began to discuss clear issues associated with automation during simulator. Before the simulation training, other themes began to diminish (e.g.,
learning SOPs as part of procedures theme) as pilots practiced these skills, while automation became increasingly problematic as pilots progressed along with the curriculum. Table 2 presents the final coding result in terms of learning automation. Pilots from Airline B (P7 – P10 in Table 2) were not followed during their ground training therefore no data was collected during that phase of training. Nonetheless, pilots from both airlines discussed similar issues during their FFS and Line Training. In addition, one pilot (P6) did not continue his training after he failed at the early stages of Full Flight Simulator (FFS) training. This section outlines emerging themes according to each training phase.

**Table 2. Result of Thematic Analysis Extracted from the Overall Study Result**

<table>
<thead>
<tr>
<th>Training Phase</th>
<th>Theme: Learning of Automation</th>
<th>Pilot Code</th>
<th>Total Pilots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground School*</td>
<td>One of the many systems</td>
<td>√ √ √ √</td>
<td>- - - - - - - 5 6</td>
</tr>
<tr>
<td></td>
<td>Adapting past experience</td>
<td>√ √ √ √</td>
<td>- - - - - - - 4 6</td>
</tr>
<tr>
<td>Part Task Trainer</td>
<td>Programming FMC with CDU</td>
<td>√ √</td>
<td>4</td>
</tr>
<tr>
<td>Full Flight Simulator</td>
<td>Understanding automation functionality</td>
<td>√ √ √ √ √</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Maintaining aircraft awareness</td>
<td>√ √ √ √</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Timing procedures to align with automation</td>
<td>√ √ √ √ √</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Applying theory into practice (breaks in training)</td>
<td>√ √ √ √</td>
<td>4</td>
</tr>
<tr>
<td>Line Training and</td>
<td>Practicing automation use</td>
<td>√ √ √ √ √</td>
<td>7 7</td>
</tr>
<tr>
<td>Checked to Line</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*Data of Airline B did not include Ground School Phase as the pilots completed the phase at University prior to the entry of the airline’s initial training program).

**Learning Journey throughout Training Phases**

*Ground School (GS)*

Close examination of text segments coded to automation, identified two themes; *one of the many systems* and *adapting past experience*. At this stage of training, aircraft systems were taught sequentially, with pilot trainees struggling to understand how they linked with one another. During this early phase of training, automation was only discussed by all pilots (Airline A) as a broad topic on the day when the program covered the automation syllabus. They did not find automation difficult; however, their discussions highlighted the automation
was embedded within the sheer amount of information presented during training, rather than from information complexity. In some cases, pilots simply needed more time to learn and absorb the information: “Electrical is a bit more difficult. It’s just a lot of parts. There’s nothing particularly hard about it, just time-consuming” (P5_GS). In other cases, having too much information left pilots feeling confused and experiencing information overload. This suggested that automation was viewed as one of the many systems that they used for flight operation that they needed to learn about, and the pilots’ confusion underlined some structural issues in the training program (i.e., enacted curriculum).

The second theme, *adapting past experience*, explained why learning automation was not problematic to a majority of Airline A pilots when automation systems were described during this stage of training. These pilots reported that their previous experience assisted them to understand the presented training materials. For example, P1 reported that his experience with flight simulators on his computer helped him to understand aircraft automation systems:

> I’ve always been involved with the flight simulator on my computer in the past. All the autopilot stuff is very easily transferable, [and its] knowledge [is] all pretty standard across the board. (P1_GS)

At the same time, this theme also highlighted a cognitive problem of moving from one to another aircraft type. For example, although P5 had flown a similar type of aircraft with a comparable automation system to the one he was learning to operate in training, he reported issues with learning the layout of the mode control panel (MCP):

> So the [MCP] is the same, same logic, [but] different layout. I struggle with the [MCP]’s, because it’s a bit hard to get your head around the [MCP] until you play with it. Especially the autopilot functions. (P5_GS)
**Part Task Trainer (PTT)**

Both airlines had dedicated version-specific automation Part Task Trainer (PTT) devices, where pilots were separated according to aircraft type. This training began by reviewing the theory of the flight management computer (FMC), then practising programming the FMC via the control display unit (CDU) contained in PTT. At this point, pilots were taught the procedures for CDU programming (motor skill, sequence, and triggers) and company standard operating procedure (verbal calls) for automation use. Two themes emerged for the PTT phase; *adapting past experience* and *programming FMC with CDU*.

Similar to the Ground School phase, a theme of *adapting past experience* emerged as pilots with previous automation experience reported finding it easy to adapt their prior knowledge to the theoretical parts of FMC systems training. However, the second theme emerged when they reported difficulties in *programming FMC with CDU*. For example, P3 described the difficulty of learning to set up a flight plan, one method for manually adding a flight plan (i.e., adding a new route) into the FMC, and the other method of getting a flight plan that was pre-programmed:

> When there’s no routes stored in the system and you want to create a new one…. But if you wanted to put in an airway that’s already stored in the [FMC], you have to press a certain key [on the CDU]. There is nothing that prompts you to press that key…Then just out of the blue, you press this other key, and then put in one of the points, and it will give you a whole lot of options. (P3_PTT)

Conversely, pilots with no previous FMC experience struggled more when programming. Their lack of experience made them rely only on theoretical content taught in the Ground School:
I understood it in the classroom, what he was talking about and how you got there. But when you actually sit in front of the machine and you start doing the process, you sort of get much like, “Where do I go from here again?” He might need to prompt us, and it’s like, “Ah, that’s right.” Then it sort of flows. (P2_PTT)

During PTT, automation is beginning to be viewed differently to other systems, requiring other skills and knowledge to operate effectively, such as procedures for programming (motor skill, sequence, and triggers) and how they are embedded within company standard operating procedure (learning verbal calls with another crew). Even though pilot trainees were taught in pairs, findings do not suggest any crew coordination. Instead, pilot trainees were observed to refer to their partners as a source of information rather than as another crew member, indicating that even at this stage, the joint cognitive system was still developing.

Full Flight Simulator (FFS)

After PTT, pilots are taught company standard operating procedures (SOPs) in a Full Flight Simulator (FFS). As part of carrying out company SOPs, pilots also begin to actively engage with automation based on their roles as either pilot flying (PF) or pilot monitoring (PM). At this point in training, the curriculum starts to reflect how joint cognitive systems might function during work, and pilots also start to learn what it means to become a component of a joint cognitive system. According to Table 2, all pilots discussed automation during FFS, with four themes emerging including; understanding automation functionality, maintaining aircraft awareness, timing procedures to align with automation, and applying theory into practice.

During the early stages of FFS, pilots were still reporting minor issues remembering how to program the FMC with CDU. Initially, the texts were coded to the same theme of PTT Phase (i.e., programming FMC with CDU). However, the re-examination of these coded texts
resulted in re-categorising them into a new theme of understanding automation functionality. That is, in the process of becoming familiar with the early set up of the FMC with the CDU (e.g., pre-departure setup) variations in flight, the pilots discussed the problem ensuring what is programmed in the FMC inflight, as well as autopilot mode selection, achieved the desired flight path. For example, P2 was a pilot without previous experience of automation, and he felt that it would have been easier to manually fly the aircraft than to program the automation, which requires multiple steps and remembering the different functions. This process could also be made more difficult when the pilot is required to direct the other pilot to make either CDU or MCP selection:

The biggest thing for me personally is the automation stuff, getting my head around that. I’m still at times not understanding it. I’m making silly mistakes because I’m not understanding what mode I need to be in…. This is like, “Okay, the change then, I’ve got to go to this page, and then I’ve got to be in this mode,” and so it’s just a lot longer process, rather than just being able to physically make the change. For me, it’d be far easier to just turn the autopilot off. (P2_FFS)

As FFS training progressed, training scenarios became increasingly complex, especially around non-normal operations. At this stage, P6 had performance issues and was removed from the course. Along with the increasing complexity of flight operation, difficulty maintaining aircraft awareness was outlined. This was exemplified when engaging the autopilot or during non-normal procedures where the aircraft flight path is controlled by the autopilot. For example, during an engine failure, pilots needed to fly the aircraft manually and correctly trim the aircraft (relieve aerodynamic forces on external flight controls so little hand control input is required to maintain desired flight path) prior to engaging automation. P8 reported losing the feel of what was happening with the flight controls.
More than half of the pilots reported difficulty timing procedures to align with automation or how aircraft automation is programmed. In some scenarios, automation dictates the pace at which specific actions must be completed. In the following example, although the automation by design is correctly accelerating the aircraft, P4 was unable to keep pace, requiring him to reduce thrust on the operating engine:

The other thing is if you don’t get it done in time, and you do level off, that’s going to stuff your flow. That’s going to make it even harder. When the thing levels off and then, you know, it accelerates and then it over speeds, and you still haven’t pulled the power back yet. You’ve kind of got to take your own initiative to pull the power back, but you’re so difficult and you’re so caught up in the flow that you kind of miss it, then the thing’s quacking at you. (P4_FFS)

Further, the interrelationship was highlighted in the text segments coded both in maintaining aircraft awareness and timing procedures to align with automation. The interrelation of themes is revealed when depicting flight operations as a joint cognitive system, where the different components (PF, PM, and autopilot) to control the flight path. From setting up the autopilot at the start of a flight, to the PF calling for the autopilot to be engaged at a specific point in flight, to the autopilot taking over the control of the flight path based on what was programmed. Pilots expressed difficulties in multi-tasking of projecting flight path with autopilot while maintaining the actual state of aircraft performance.

Exercising SOPs during emergencies also resulted in them losing such awareness. In the following excerpt, P3 recalled requesting the autopilot to be engaged during an engine fire scenario. Here, even though the engine is on fire, it is still producing take-off thrust until the pilot correctly identifies and shuts down the engine, compared to an engine that fails and stops producing thrust:
I may have got it mixed up with my single-engine or engine flame out procedures as soon as we set the VFTO. Then we just engaged the autopilot, I mean the engine flame out. That’s what I did during the engine fire. The problem is, two engines you’re blasting out and we’ve set it in to [maximum continuous thrust power], so we’ve got even more power. We’re still on two engines, and the flight director is pointing at 17 degrees pitch up. As soon as you engage the autopilot you start to pitch up 17 degrees nose up. When it’s not what you’re supposed to do, you’re supposed to maintain 9 or 10 degrees, until you cut the engine and then just drop back down to a lower attitude on the flight director. Then you can engage the autopilot. (P3_FFS)

The fourth theme was associated with applying theory into practice. That is, providing information on the different modes theoretically, without allowing pilots to put them into practice immediately leads to gaps in knowledge at later stages of training. For example, due to training structure, holidays, or equipment availability, training sessions would sometimes have extended breaks. When this occurred, pilots reported having difficulty remembering how to program the FMC and recalling its functionality. P7 and P8 both struggled to remember how to program the FMC during the simulator exercise, as the last time they had used the FMC was during their systems training at university, which was nearly one month ago.

We did [FMC] when we were at [university], so that would have been a good three weeks before we even started here…. The FMC programming…. I was really scratching my head thinking, “How do I do that again?”…. Because all the sims up to now—no FMC. (P7_FFS)

Due to the extended break, P8 also could not remember how FMC and MCP function during non-normal situations, having forgotten “all these obscure little rules that kind of, don’t make logical sense [during systems training]” (P8_FFS). This problem presented itself
halfway through FFS training when non-normal scenarios were being introduced. P8 explained that the various types of automation modes for the FMC were presented on the computer-based program but had not been practiced until that particular simulator session. The sudden need to recall the differences in mode functionality during non-normal training sessions was not intuitive.

What appears clear is that even at the latter stages of FFS training, where pilots are about to be given their country’s regulatory endorsement to fly this aircraft, there remains some level of confusion surrounding automation use. Nonetheless, the descriptions provided by pilots at this phase of training suggest they had started to view each other and automation as part of one joint cognitive system.

*Line Training and Checked to Line*

At the final phase of the training, most of the pilots said line training with a training captain afforded them an opportunity to *practice automation use*. The pilots agreed that the opportunity to practice using automation in various situations during line operations had been beneficial, even for those who had not reported any issues with automation during simulator exercises. Particularly, P7 stated that automation was covered at a basic level, but he did not discover the more complex aspects of automation until he began line training. He described that when automation became too confusing during flight, he disconnected the autopilot and flew the aircraft manually:

> Being exposed to it more has been helpful. In the sim[ulator] it was a lot about manual handling of the aeroplane, that was really what a lot of it was. There was a little bit on the automation [which] you just kind of picked up as you went. Unless you’re really exposed to all these random little mode changes…[sometimes] you’re having to just disengage the autopilot completely and just hand fly it. (P7_LT)
Even after being checked to line, pilots reflected on having learned new things around automation. For example, P7 remembered the initial shock he felt in a situation when the autopilot disengaged during turbulence:

The Dash8 doesn’t handle [turbulence] that well, and the autopilot will just disengage….

[When] the first time that happened…, I didn’t know what happened…. But now it happens relatively regularly, and it’s almost like a non-event now…It’s like, “Okay, it’s really bumpy, the autopilot may disengage.” If it does, you just hand fly it for a bit, get it back under control, and just reengage it. (P7_CTL)

In general, pilots said that when it came to learning about automation, practice was key. However, there were still times when functionality was an aspect of automation that could be surprising, especially in different scenarios.

When you put it back into the CDU and say, “I want to track direct to the field rather than going out and around,” the plane wants to nosedive. It goes into a mind of its own. The FMC goes, “Oh, if I want to get to the field at this height, I really need to put the nose down and descend at a really high descent rate, right?” So everything’s happening. [The aircraft is] maintaining straight and level flight, the FMC changes, and then all of a sudden the aeroplane just goes into a turn and just nosedives. (P9_CTL)

P9 further went on to describe the need to better understand the vertical navigation (VNAV) function and how to properly use it in different scenarios to prevent the above situation from happening.

Discussion

Through thematic analysis of pilot interviews, eight themes emerged regarding the process of learning automation. It includes (1) one of the many systems, (2) adapting past experience, (3) programming FMC with CDU, (4) understanding automation functionality,
(5) maintaining aircraft awareness, (6) timing procedures to align with automation, (7) applying theory into practice, and (8) practice automation use. These themes show a shift in how pilots perceived their mastery of automation throughout training and describe how new pilots learn automation as part of a joint cognitive system. More specifically, initial computer-based training appeared to reveal minor issues. As trainees began to use automation there was an increasing level of uncertainty (i.e., FMS functionality and mode use) during simulator training; however, an opposite perception was shared when pilots began line training in the real aircraft.

The detailed description of these pilots’ learning automation highlighted four key issues associated with automation. It includes (1) difficulties programming the FMC via the CDU, (2) flying the aircraft with the automatic pilot from inputs on the MCP, (3) working with another pilot and the automation system, and (4) the gaps in automation functionality knowledge. These issues appear to be aligned with those highlighted in the existing literature.

First, the findings suggest the pilots experienced difficulties programming the FMC via the CDU. The pilots learned about aircraft automation systems during ground training and gained practical experience during part task training and simulator training. In ground training, automation was taught through computer-based training, which was the same mode of instruction used to teach other aircraft systems such as the electrical and hydraulics systems. During part task training, the pilots learned how to operate the FMC through the CDU; however, findings suggest that some pilots who had limited experience with automation before training did not receive adequate practice and/or instruction. Conversely, pilots with previous experience using automation did not have many issues with its use during training.
Second, the findings showed that some pilots struggled with *flying the aircraft with the automatic pilot from inputs on the MCP*. That is, these pilots had difficulty operating the aircraft when they were required to use the autopilot to control their flight path. For example, making a turn while manually flying is a simple matter of turning the control column and looking at the PFD and ND. However, performing this task using the automated system requires the pilot to “engage autopilot,” select “heading mode,” and turn the “heading dial to the required heading”. In these cases, using automation did not decrease but rather increased pilots’ workload, as some pilots found it easier to fly the aircraft manually in the early stages of FFS training. The evolution of flight deck designs and automation systems has changed how pilots conduct flight management. Now, instead of manipulating the aircraft using “stick and rudder” skills, pilots have to program the aircraft to follow a specific flight path. However, only when actions or programming are conducted in accordance with the logic or functionality of the automation system, and with the correct sequence, will the aircraft fly as anticipated by pilots (Chialastri, 2012).

Third, the findings indicate that many pilots encountered new issues when they started simulation training where they had to *work with another pilot and the automation system*. As discussed in the previous section, learning how to program a flight path through the MCP was problematic. In most SOPs, there is an additional complexity when the pilot is required to make inputs via the MCP or CDU but has to command the other pilot to make these actions. The process of controlling the aircraft flight path management is now compounded with issues of automation and crew coordination. Considering the influence that automation has on multicrew collaboration (e.g., Wiener, 1988), this is an obvious area in which automation should take a prominent place, both practically and conceptually (Rigner & Dekker, 1999).
Fourth, the pilots’ comments highlighted *the gaps in automation functionality* knowledge during training due to lack of practice or lack of understanding of the automated system, especially when there were long breaks between when automation concepts were taught and when they were practiced. In this study, pilots experiencing advanced automation for the first time found automation particularly difficult to grasp, initially understanding the theory when presented as text or pictures but having difficulty when required to enact what was taught. Conversely, pilots who had used automation in the past had fewer issues understanding and remembering. Research has found that pilots with no experience of automation could be proficient in automation use if training curriculums adequately explained the functionality of automation in addition to button-pushing procedures (Casner, 2003a). However, emphasis on functionality is required during those sessions. If teaching focuses only on procedures and rote learning (e.g., actions to program/use automation), then brittle skills are learned, and pilots will find it difficult to cope with situations different from what was taught during training (Casner, 2003a).

Moreover, the findings suggest that when pilots had transitioned to the real-world environment (i.e., line training), they were equipped only with a basic understanding of automation usage, having to learn the bulk of automation systems as they conducted daily flight operations with their training captain. This corresponds with Wood and Huddlestone’s (2006) findings on the state of current pilot training programs, where there is a gap between the procedural knowledge required to operate highly automated aircraft and current training practices. Pilots in this study reflected that automation functionality was taught at the very start of their ground training and was only briefly practiced at later stages of training (i.e., FFS training) when they started practicing SOPs. This also meant that only specific aspects of automation functionality were reviewed during FFS training exercises, typically only when they involved a particular type of SOP (e.g., how vertical flight path functionality changes
during non-normal scenarios such as an engine flameout). These findings are aligned with other research indicating that pilots have inadequate knowledge of systems functionality and that training for automation needs to be improved (FAA, 2013; Holder & Hutchins, 2001; Strauch, 2017; Wood & Huddlestone, 2006). Research by Soo et al. (2016) demonstrated that even highly experienced pilots can make mistakes around automation functionality.

To understand and use automation, pilots must be able to grasp the functionality, or logic, behind the automation system, to be skilled at interfacing with automation via both CDU or MCP inputs, and to be able to receive and understand the provided information (Soo et al., 2016). While pilots can make decisions and communicate with each other, often through verbal means, automation can also make decisions and relay them to the pilots via the CDU, MCP, PFD, or ND, or through auditory methods (e.g., trim). Pilots’ difficulties working with automation and with another pilot are aligned with the training needs highlighted in the literature: The automation system should be considered as a third agent of control in the flight deck within the joint cognitive system, along with the captain and first officer (e.g., Degani et al., 2017). Hence, the training of automation should reflect how it should be used and understood like another crewmember.

Adopting the idea that automation is another team member implies that training practices should include automation use more holistically in its objectives, including crew resource management training (Taylor, 2018). However, the design of automated systems in the flight deck makes collaborative communication difficult (Taylor, 2018). Until automation systems are designed to become more human centred and considerate of team play capacities (Christoffersen & Woods, 2002; Sarter & Woods, 1997), pilots will continue to need a deep understanding of the various automation functions and functionalities, and the modes of communication afforded by automation.
Curriculum theory and interventions for Improving Automation Training

This study employing curriculum theory highlighted the dynamic interrelations among three aspects of intended, enacted, and experienced curriculum, which provided insights into effective and ineffective aspects of the program for pilots to master automation during their initial training (Billet, 2006). More specifically, observations and document review reported what training structure, methods, and strategies were used in the program (enacted); and thematic analysis of interviews informed what aspects of the program these pilots valued the most and the least in terms of mastering automation (experienced) to achieve learning objectives listed in the training documents which were developed in alignment with regulatory requirements and company standards (intended). Inspecting pilots’ positive comments about training experiences (i.e., what aspects of the program they liked or what they found easy) highlighted effective training aspects while exploring negative experiences (i.e., what aspects of the program they disliked or what they found difficulties) revealed ineffective training aspects. Accordingly, four areas of recommendations were suggested: (a) automation should not be taught like another aircraft subsystem, (b) automation should be taught as a spiralling curriculum, (c) additional practice tools should be provided, and (d) improved prescription on use of modes in the early stages of training is recommended.

Automation Should Not be Taught like Another Aircraft Subsystem

The findings of the study support the suggestions of Rigner and Dekker (1999) about how automation should not be taught as equivalent to other aircraft subsystems but in a way that is representative of pilot work. As most actions taken by pilots would involve automation in some form or other, their interactions and role as a third pilot (Sarter & Woods, 1997) should be emphasized. The present study stressed the importance of teaching new pilots the
function and functionality of automation. What is fundamental is that automation systems *think*, and the understanding of this functionality (thinking) is critical to safety (Soo et al., 2016). According to Casner (2003b), automation proficiency is a “unique set of skills that must be learned in addition to basic airmanship” (p. 11); therefore, it cannot be assumed that more time in line operations would lead to the proper and deep understanding of automation.

*Automation Should be Taught as a Spiralling Curriculum*

The study emphasized that practice was important not only in retaining knowledge and skills but also in learning increasingly complex automation functions. As such, the training syllabus should be carried out based on the spiralling curriculum format (Bruner, 1996). The aim is to introduce automation theory and practice from the very beginning of training with an emphasis on a joint cognitive system structure and revisit them several times as training progresses through the different phases, with the complexity of training content or activity increasing with each session.

*Additional Practice Tools Should Be Provided*

The airlines also recognized that the current practices of teaching automation by rostering pilots for part task training in a flat panel trainer, FFS, or real aircraft were not sufficient. However, the airlines had neither access nor resources to expand the current training course. Therefore, they looked for alternative teaching tools that were cheaper, but that had adequate fidelity with part task training devices. For this purpose, Airline A sourced a tablet-based program that enables pilots to practice automation inputs through a CDU and that also provided PFD, ND, and MCP visibility.

*Improve Prescription on Use of Modes in Early Stages Training*
During training, many airlines allow pilots to determine when and how to use automation (Barshi et al., 2016). This is problematic during the early stages of training because most pilots do not yet have sufficient experience to use automation appropriately or to maintain a balance between practicing automation and learning to hand fly the aircraft (Casner et al., 2014; Ebbatson et al., 2010; Haslbeck & Hoermann, 2016; Haslbeck et al., 2014). Therefore, pilots should be provided with ongoing guidance and advice as they practice using automation and also learn to disengage automation, in diverse situations that highlight a variety of tasks and operational constraints (Durso et al., 2015; Mosier et al., 2013).

Both airlines, therefore, moved towards providing greater scaffolding during briefings prior to FFS, rather than simply leaving it to pilots. These briefing included: (a) FMC set and CDU inputs required prior to each sequence, (b) what MCP buttons should be used for each sequence, and (c) the use of actual pictures of what to expect, such as PFD, ND, MCP, and CDU.

Conclusion

Aircraft automation systems and related components have advanced exponentially over the years. Many researchers have suggested that automation should not be treated as some subsystem as part of training, but rather as a team player in the flight deck. However, training of these aspects has not seen equivalent growth, resulting in the same issues revealed in the past being prevalent even today. This longitudinal study has revealed that current training practices were only enough to educate pilots to just a basic level of understanding of the operation and functionality of automation. We used curriculum theory to inspect how pilots learn automation and considered their learning process using the concept of joint cognitive systems to understand and also describe how pilots construct an understanding of
functionality and how they interact with it. The findings have shown the difficulties that pilots experience in mastering automation, suggesting the need for improvements for the current training practices to develop pilots’ mastery of automation.
References


Federal Aviation Administration (2013). *Operational use of flight path management systems: Final report of the performance-based operations aviation rulemaking*
committee/commercial aviation safety team flight deck automation working group. Washington, DC: Author.

Harris, D. (2013). Distributed cognition in flight operations. In D. Harris (Ed.), Engineering psychology and cognitive ergonomics applications and services (pp. 125-133). Springer.


Biographies of authors:

Dr Kassandra (Kass) Soo completed her honors in psychology in 2015 investigating mixed fleet flying in regional aircraft. She completed her PhD at the Griffith Institute for Educational Research (GIER) in Brisbane Australia, conducting a longitudinal study into the learning and development of new pilots into airlines.

Dr Tim Mavin is an associate professor at the School of Education and Professional Studies and a member of GIER, and currently holds the rank of Wing Commander in the Royal Australian Air Force. He has over 10,000 hours of flight time, worked as an airline captain, Boeing 737 simulator instructor, flight operations inspector, and is a registered schoolteacher in Queensland. He has over 50 publications in books, journal articles and book chapters relating to education and training.

Dr Yoriko Kikkawa is a research fellow at GIER. Yoriko has been assisting research students and early career researchers as a qualitative methodology consultant at Griffith University since 2012. Yoriko conducts cross-cultural, cross-sector, and cross-disciplinary research. She has investigated school teaching practices across cultures, simulator-based training with airline pilots, understanding workplace accident in elevated-work platforms in the Australian Construction Industry, and simulator-based training in emergency maternity medicine.