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Testing Backward Chaining Ab-initio Flight Instruction

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This conceptual/exploratory follow-on study was undertaken to further answer on the question: could backward chaining, in a flight simulator prior to first flight, accelerate a student pilot's (STD) ability to solo by reducing the amount of dual-instruction time required prior to solo flight? The previous research installment was published by Vance, Gardner-Vandy, and Freihoefer (2021) in the Journal of Aviation/Aerospace Education and Research (JAAER) Vol. 30, Issue 1. The current, follow-on research was structured to explore this question as close to identically as that previously accomplished while leveraging and incorporating the lessons learned on the first research installment, and further exploring the question with a new round of respondents. Additionally, a comparison was also undertaken between the conceptual/exploratory backward chained flight instruction methodology and that with the more traditional forward chained flight instruction methods. In the first research installment, four respondents were recruited and employed. Eight additional respondents were recruited and employed in this second research installment, four in backward chained instruction and four in forward chained instruction.

Explanation of study rationale/purpose – The overall research purpose was to explore an idea that could be of potential benefit to ab-initio flight students – would teaching them to land the aircraft first accelerate their flight training? Secondarily, would it motivate STD to continue their flight training? The immediate desired observational outcome from this research was the STD sole manipulation of the controls of an actual aircraft on their first flight lesson, completing three circuits in an airport traffic pattern without the accompanying Principal Investigator's (PI)/Certified Flight Instructor's (CFI) physical, flight control intervention (note: Table 3 in the Results section documents the actual STD-completed landings: one STD completed four landings, eight STD completed three landings, two completed two landings, and two completed one landing). A longer-term research outcome would be the determination if the exposure to landings instruction first reduces the time required to solo.

The original motivation for this research was the PI's exposure to the concept of backward chaining in initial flight instruction at the fall 2017 University Aviation Association conference and recognition that at our institution, no FAR §141 STDs were completing their solo lesson on schedule; rather all were requiring multiple repeats of landing lessons prior to solo incurring additional STD cost and slowing STD training pace.

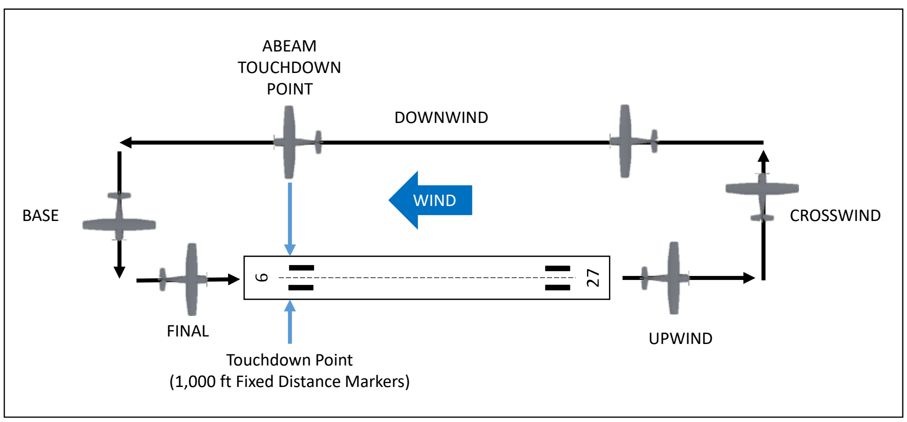
In addition to encouraging other institutions/flight schools to initiate similar experimentation, further purposes of this paper are to report on the second experimental group of four STD's backward chaining results, update backward chaining methodology, compare of the backward chained STD with those that were exposed to forward chained flight instruction, analyze and summarize each STD performance, and discuss observations and learnings from conducting this exploratory research.

Definitions and distinctions between backward v. forward chaining – Chaining refers to learning by taking a complex task and breaking it into a series of individual steps (Olson, 2002). These steps can then be taught and mastered individually. Backward chaining is simply the reverse sequencing of a series of steps, which are normally taken in a chronologically, sequential, "forward chained" manner

(Rouse & Hough, 2018). Forward chaining is therefore learning by teaching the series of sequential tasks starting from the initial step, then teaching the additional steps in chronological order (Slocum & Tiger, 2011). Forward chaining is how most teaching occurs, teaching from start-to-end in chronological order. Learning to fly is typically taught in a forward chaining approach, where negotiating a standard Federal Aviation Administration (FAA) traffic pattern (Figure 1) is taught forward chained in nearly every flight school (Olson, 2002). In forward-chained flight instruction, the last task to be mastered prior to solo is landing the aircraft.

At our collegiate institution, a records pull of 49 students over a three-year period (01 Aug 2017 - 01 Aug 2020) showed for our 12-lesson, pre-solo curricula, scheduled at 11.5 hours of dual instruction, no student completed the pre-solo lessons within the scheduled 11.5 hours; rather, the μ = 19.9 hours with σ = 4.7 hours. On average, each student required 7.2 hours of additional dual instruction, given in six or more lessons, dedicated to landings. Thus, the vast preponderance of the overage, while not unique to landings, was dedicated to landings practice.

Figure 1
Orientation and Layout of the Standard FAA Airport Traffic Pattern, Including Nomenclature for Each Leg: Upwind, Crosswind, Downwind, Base, and Final (Approach)



Applied to pre-solo, ab-initio pilots, instead of teaching them to land an aircraft as the final significant task to be mastered prior to solo, could teaching them to land an aircraft first accelerate their training and lower the time required to solo? Backward chaining reverses, or flips, the typical approach taken to teach flying over the last 100+ years.

The research-employed method of backward chaining flight instruction started the STD over the runway, on a standard FAA 3° glide path, at 4 feet above ground level (AGL) altitude and 80 feet behind the behind the beginning of the 1,000 foot fixed distance runway markings (see Figure 1.), the intended point of landing. The STD was then successively iterated at starting points of appropriate altitude and distance around

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the legs of a standard, rectangular FAA airport traffic pattern, in reverse sequence: Final Approach, Base, Downwind, Crosswind, Upwind, and finally, Take-Off.

The forward chaining method of instruction started the STD on the runway surface, at a normal take-off position, to fly the standard FAA airport traffic pattern in traditional sequence: Take-Off, Upwind, Crosswind, Downwind, Base, Final Approach, and Landing.

Research Question(s) - The original posed research question (RQ1) was: If a STD with no prior flight-training experience is first taught to land the aircraft in a simulator via a backward-chaining approach, will this reduce their dual instruction hours required to solo in actual aircraft? RQ1 was truncated in this research installment to explore only the STD's ability to fly, unassisted, a standard FAA airport traffic pattern. RQ2 was added in this research installment to explore whether a difference could be detected between a backward v. a forward chained approach to accomplishing RQ1. Specific wording of both research questions follows:

- RQ1 - If a STD with no prior flight-training experience is first taught to land the aircraft in a simulator via a backward chaining approach, will this permit them to complete unassisted, three circuits in a standard FAA airport traffic pattern in an actual aircraft?

- RQ2 – Is there a perceptible difference in ability to complete unassisted, three circuits in a standard FAA airport traffic pattern in an actual aircraft if the STD is first taught to land the aircraft in a simulator, with a forward chaining approach instead of a backward chaining approach?

Problem Statement

Would conducting the previously-employed backward chaining research in a second installment be repeatable? Would the results be similar, identical, or dissimilar, and what further learnings could be advocated? Would the backward chained results be comparable to those from a more traditional, forward chained flight instructional approach?

Literature Review

Abbreviated Summary – In our overall literature review of this topic, while there are numerous backward chaining applications outside of aviation, we found no consistent methodological approach for analyzing backward chaining in an ab-initio flight training environment. The singular, most-relevant example identified was a study conducted by Lintern et al. (1990) at the University of Illinois, Urbana-Champaign, IL. Two, one-hour simulator sessions along a virtual final approach corridor, concluding with 26 landings resulted in shaving 1.0 hours of dual instruction received from the control group's 18.6 hours. This study did not incrementally backward chain the respondents, rather all were repeatedly started from a point in space 10,100 feet from the runway threshold at an altitude of 635 feet.

Historical use of flight simulation, flight training instructional methods, and Competency-Based Training (CBT) are also reviewed to set a value context for backward chaining in ab-initio flight instruction.

Backward Chaining Outside of Aviation – Applications of backward chaining are prevalent outside of aviation and include: machine learning (Al-Ajlan, 2015), teaching of basic skills to children, non-adults and adults physical and mental tasks (Jerome & Sturmey, 2007; Slocum & Tiger, 2011; Kobylarz et al., 2020), weight lifting to adults (Moore & Quintero, 2018), vocational tasks to adults with disabilities/children with eating disorders (Rubio et al., 2017), creating launch rules for NASA (Rajkumar & Bardina, 2003), improving decision making for local flood forecasting (Zhang et al., 2018), and expert systems for early detection and diagnosis of central nervous diseases (Paryati & Krit, 2022).

Historical Use of Flight Simulation – Light aircraft flight instruction has historically been delivered in a forward chaining context where learning to fly is a sequential building of knowledge and demonstrated skill tasks, starting with taxi and takeoff. Learning to land has been typically one of the final tasks to be mastered prior to solo. Studies consistently have observed, "….the basic structure of the pilot training and licensing system has not changed considerably since World War II" (Todd et al., 2013, p. 169). Barata and Neves (2017) also reiterated this theme. In the last 40 years, however, simulation has become progressively more capable and affordable for incorporation into General Aviation flight training; but, significantly, is rarely used to teach pre-solo students (Ennis, 2009; Goetz et al., 2012).

A dedicated effort was made by Goetz et al. (2012) to explore the reduced-time-to-solo with forward chaining, pre-solo simulation; however, the experimental results, mean-time-to-solo of 17.1 hours and 77 days compared with the control group's mean-time-to-solo of 17.4 hours and 86 days, were not statistically significant. McLean, et al. (2016) conducted a similar study with 29 students in the experimental group receiving simulation training and 62 students in the control group. While the results showed statistical significance with a savings of 1.3 hrs. of dual instruction to reach solo (14.7 for the experimental group v. 16.0 for the control group, who did not receive simulation training), this is an operationally small difference. When the total time invested to solo (simulation + actual aircraft training) is compared at 21.2 hours. versus 16.0 hours, the resulting Transfer Effectiveness Ratio (TER) = 1.3/6.5 = 0.2, is small; and significantly for comparison with this research, none of the simulation involved landing the aircraft.

Macchiarella et al. (2006) was able to generate an average task-based TER of 0.5 with 20 ab-initio flight students who received 60% of their Private flight training in a simulator compared to 18 students who received no simulation training. This simulation training involved both landing and pattern instruction; and while the reduction in task iterations was generally impressive for these tasks at over 50% for the experimental group, the research was not explicit about whether or not these tasks were completed pre-solo.

With localized exceptions, simulation is generally not employed in pre-solo general aviation flight training (Brady, 2001; Page, 2000). An established, successful FAR §141 school, contacted in support of this research, is notable for its recently implemented, pre-solo, simulation curricula that is required for their ab-initio students. With embedded simulation, prior to solo, this school had reduced the flight time required to solo from 18.0 hours dual instruction received in their aircraft to 10.0 hours (a TER of 1.0). This pre-solo simulation work, however, is not backward chained.

Backward chaining appears to be a training technique that, while it enjoyed some popularity in the 1970s and 1980s, is no longer easily locatable in the flight training literature. No published flight training examples of backward chaining were located after 1996.

Flight Training Instructional Methods – For about the last 20 years, flight training has been transitioning from a historical task basis to a blend of task and competency basis (Fanjoy, 2000). This is an important development highlighted in adult-learning styles which focus on successful aviation outcomes by balancing mastery of sequential tasks with knowledge, assessment of risk, and demonstration of these skills in scenario-based settings (Brady et al., 2001; Watkins et al., 2016).

This task and competency blend is commonly referred to as Competency-Based Training (CBT). Kearns et al. (2016) details the concept of competency-based education in aviation, noting the importance of quality of training over quantity of training hours, and pushes for the standardization of knowledge, skills, and performance. Melvin (2018) offers a concise CBT definition, overview, and statement of benefit. Even though the approach of balancing tasks with competencies makes inherent sense, especially as automation is so prevalent in modern cockpits, the infusion of CBT into the flight training transition does not appear complete nor as widely implemented as might be expected (Burgess, 2016).

Similar to CBT, backward chaining, as applied in this exploratory research, was also outcome-focused and required more than simple skill repetition. Initially, the immediate outcome was landing the aircraft, but as the student was successively backed-up around a standard FAA traffic pattern, in addition to always concluding with a landing, the outcome shifted to the student's decision-making ability to balance pitch attitude, airspeed, and glide path as they negotiated a standard FAA traffic pattern circuit. The student was with each iteration applying their ability to sense what was required of them to maintain traffic-pattern integrity, proper flight path management, and to execute a landing.

The FAA's shift from its Practical Test Standards (PTS) to Airmen Certification Standards (ACS) (FAA, 2017) shows a dedicated effort to accentuate a risk-based assessment approach to pilot certification. This shift is consistent with competency-based training (CBT) which has also been endorsed by ICAO (Todd et al., 2013). Teaching risk assessment from the moment a pilot starts flight training is consistent with both the PTS and CBT philosophies of focusing on the broader skills of decision making while complimenting the more mechanical, task-based skills of manipulating the controls of an aircraft CBT focuses on the learner's ability to receive and respond to information to achieve competency. More specifically, it is "concerned with training to industry specific standards rather than an individual's achievement relative to others" (ACCI, 1992). The FAA has demonstrated this shift in their adoption of the ACS over the now out-of-date Practical Test Standards (PTS) (FAA, 2017). The ACS "adds task-specific knowledge and risk management elements" (FAA, 2017) to a pilot's certification requirements.

The employed backward chaining approach to teaching landing is potentially valuable in the CBT context that it forces the STD to assess very early in their flight training deviations from desired flight paths, project trajectories/take proactive actions to recover, and mitigate the risk of being out-of-position laterally, vertically, or both. Especially valuable would be the ability to recognize and correct simultaneously too low in altitude and too slow in airspeed situations. This is an investment from the moment their flight training begins in the critical safety-of-flight skills of situational awareness, risk assessment, and risk mitigation. These skills, learned earlier in flight training, could be a STD flight training accelerant.

Methodology

This section includes an overall methodological description of the backward chaining procedure (including adjustments from first research installment), forward chaining set-up, STD recruitment, emphasis on the delivered ground instruction, both classroom and simulation prior to In-flight instruction, flying in the simulator/aircraft, and analysis methods of the STD's performance.

Backward Chaining Set-Up – The backward chaining methodology employed in this second research installment was identical to the first research installment with several minor improvements and one potentially significant change: increasing from two to three, simulator sessions. The same steps as used before were accomplished in this order: 1) recruit and select non-flight experienced STD, 2) orient selected STD to research objectives, principals of flight/basic aircraft control in a one-hour ground instruction session), 3) fly STD in the simulator, and 4) fly STD in an actual aircraft The identical iteration start point definitions and pattern profile were reused. The recruitment of Research Assistants (RA)/Safety Observers was a valuable lesson learned from the first research installment as a prudent and necessary safety enhancement, and with one exception, was employed on all subsequent research flights.

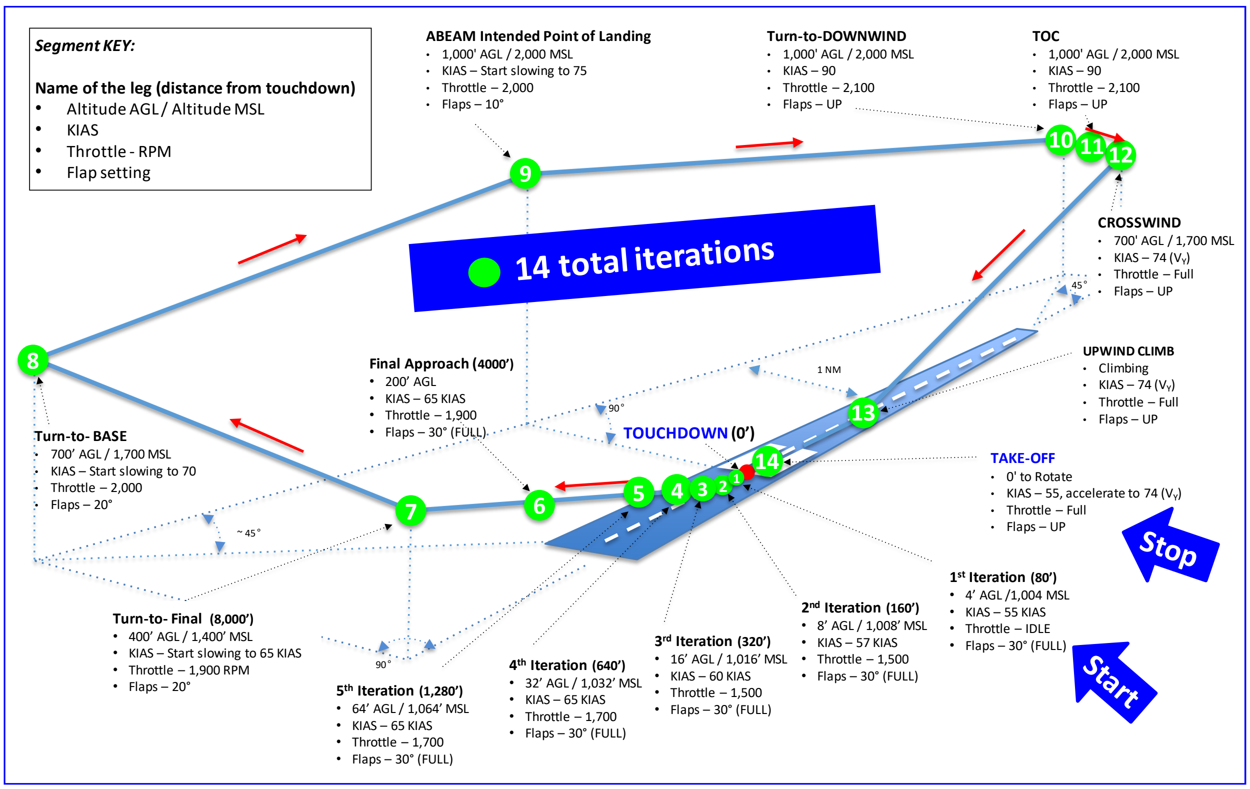
The simulator employed was the only one available on location, a Redbird MCX configured as a C-172S with Garmin G1000 avionics. This device is technically classified via FAA Advisory Circular 61-63B (FAA, 2018a) as an Advanced Aviation Training Device (AATD). An AATD does not meet the FAA definition for a flight simulator; however, for discussion continuity in this paper, the Redbird MCX will henceforth be referred to as a simulator.

Figure 2 shows the complete backward chaining approach of 14 iterations (numerically sequenced in the order performed and denoted with a green sphere and associated number) as the STD was intended to experience in the simulation events, starting with iteration 1 at 4 feet altitude and displaced 80 feet back on the runway from the beginning of the 1,000 feet Fixed Distance Markers (compliant with a standard FAA 3° glide path). In addition to the iteration number and distance from the touchdown point, each iteration also includes a set of starting conditions and aircraft parameters (Altitude [AGL], Knots Indicated Airspeed [KIAS], Throttle, and Flap settings) which were communicated and displayed to the STD immediately prior to the start of the respective iteration on printed placards.

The red arrows show the successive progression backwards through the standard FAA traffic pattern, from Final Approach, to Base, Downwind, Crosswind and Upwind legs. Starting with the 6th iteration, each data block also includes the standard FAA traffic pattern nomenclature. All other points were determined by the rectangular shape of a standard FAA traffic pattern, and/or the performance of the utilized C-172S aircraft.

Figure 2

All 14 Backward Chaining Iteration Points and Their Associated Starting Conditions are Shown Here Identified Numerically from 1-to-14, in the Order Experienced by the STDs



Based on the first four backward chaining STD experiences (Vance et al., 2021), three methodological adjustments were incorporated:

- As they were not adding value to STD learning, iterations 11 and 13 were not planned for further inclusion as starting points.
- Change from two 1.5-hr simulator sessions, to three 1-hr simulator sessions. The feedback from the first research installment was that too much was being expected of the STD in the second/final simulator session. Expanding

the second simulator session into two sessions allowed the third session to focus on forward chaining the steps to fly the traffic pattern.

- Inclusion of wind in the simulator training. Only a headwind was used in the second simulator session. Real-world winds occurring at the time of the third simulator session were used in the third simulator session to better prepare the STD for the actual aircraft flight to follow.

Forward Chaining Set-Up – The forward chaining methodology follows the iteration points shown in Figure 1, but only included one starting point, iteration 14, the Take-Off. A traditional flight training approach was used in the simulator where the RA instructor demonstrated one (or two) pattern circuits before releasing the simulator controls to the STD. The STD was then verbally coached on the appropriate aircraft attitude, power settings, speeds, altitudes, flap settings, and turn points on the successive pattern legs experienced in the traditional manner: Take-Off, Upwind, Crosswind, Downwind, Base, Final Approach, and Landing. The PI observed all forward chaining instruction in the simulator and occasionally intervened to offer counsel, aircraft situational awareness, and basic aircraft control pointers to the STD.

Redbird Start Points – The calculations necessary to program each of the Redbird MCX backward chaining start points were predicated on the airspeeds shown in Figure 1, a double standard rate turns (6°/sec v. the traditional 3°/sec) and with published Cessna 172S POH (Pilot's Operating Handbook) performance calculations for takeoff distance and rate-of-climb. For each iteration point, the radial/straight-line distance and angular orientation from the runway threshold for a standard, rectangular FAA traffic pattern laterally spaced 1 NM from the runway were required to program the Redbird MCX starting conditions. A one NM lateral spacing was chosen as compliant with guidance contained within the FAA Aeronautical Information Manual, paragraph 4-3-1 (FAA, 2020) and Ch-7 of the FAA Airplane Flying Handbook (FAA, 2018b).

The Redbird MCX was configured as a C-172S with G1000 avionics suite. Each of the iteration points included the following parameters: a) iteration step number and name, b) aircraft pitch attitude in degrees above or below horizon, c) airspeed (KIAS), d) altitude above Mean Sea Level (MSL), e) heading (° Magnetic), f) RPM (throttle setting), and g) flap setting (either 0°, 10°, 20°, or 30°). Unfortunately, the employed Redbird MCX was not capable of accepting instantaneous start conditions for airspeed (defaulted to 0 KIAS), aircraft pitch attitude (defaulted to 0°), or throttle/flap/trim settings (defaulted to closed/UP/Neutral, respectively).

STD Recruitment – No changes in the backward chaining recruitment protocols were made for this second research installment. As was done in the fall 2019, a solicitation was made at the fall 2021 program-mandatory, start-of-the-semester, All-Pilots meeting. The solicitation detailed the required criteria (adult, of at least 18 years of age, ProPilot declared major student, and no previous flight training experience) and preferable criteria (minimal-to-no exposure to flight simulation programs or games, no previous exposure to light, general aviation aircraft, and no previous (pilot) flight time in any light, general aviation aircraft). Airline travel was considered not a material factor and thus was not included as a criteria.

The forward chaining research occurred during the spring academic semester. There were no professional pilot program STDs that had not already begun their initial flight training at that point in the academic year; thus, the research team was required to outsource beyond the collegiate flight program. Four engineering STDs, with no previous flight training experience, were recruited and retained. With the exception of academic major, criteria for these STDs were unchanged from the previous research installments.

All eight current participants met the required criteria and the complete set of preferable criteria. The research team made the final participant selection based upon the applicant's schedule availability.

STD Orientation to Flight – A similar investment, as was conducted in the first installment of this research, included a one-hour, classroom orientation to flight. Topics covered in this session included: a) an explanation of backward (v. forward) chaining, b) research objective, c) the standard FAA airport traffic pattern, d) principals of flight/basic aircraft control, and e) flight/cockpit controls orientation. The classroom session was customized to focus on either backward or forward chaining as appropriate to the STD pool. Two important points were added to the orientation discussion:

- Differences between automobile steering wheel inputs/effects and those of an aircraft control yoke – ensuring the students understood the difference between holding a deflection of an aircraft yoke (roll rate) v. holding a bank angle (rate-of-turn) v. a deflection in an automobile steering wheel (rate-of-turn).
- Emphasis on the absolute importance of and how to balance aircraft pitch attitude/glide path with throttle RPM to maintain 65 KIAS airspeed on final approach until landing on the runway was assured – defined as the ability to land on the runway with a total reduction in power (throttle) to idle.

The RA employed in the forward chaining experimentation developed and used an enhanced version of this presentation for the forward chaining orientation. All points covered in the previously used presentation were still present, with the exception that the backward chaining relevant material was removed. Additional slides added a) imagery depicting the aircraft spacing 1 NM from the runway on the downwind leg and proper visual indicators on final approach (the latter shown in Figure 3), and b) an animated section exemplifying and demonstrating the difference between an automobile's steering wheel effects and those experienced with an aircraft control yoke. Figure 4 is an excerpt of this animation.

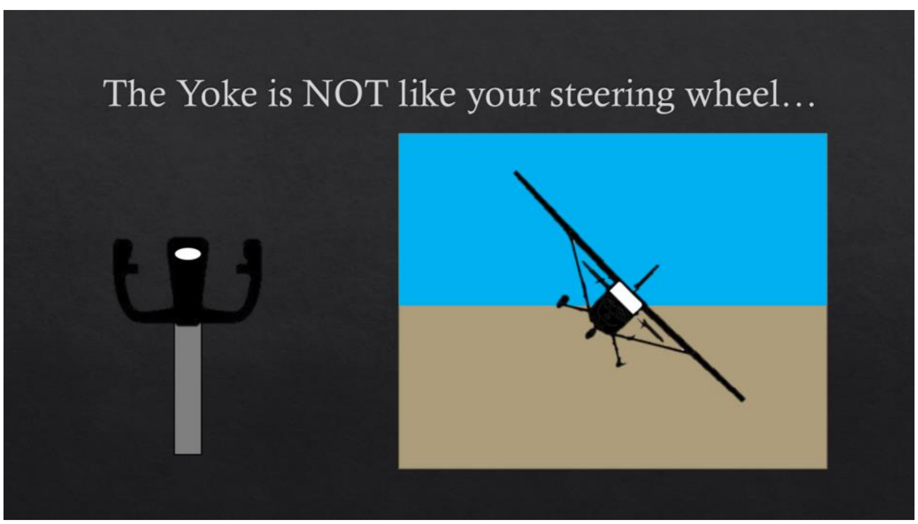
Figure 3

Added Image to the Forward Chaining Orientation Presentation.

Note. This Microsoft Flight Simulator 2020 image depicts the aircraft on glide path, on short final to land and highlights the Precision Approach Path Indicator (PAPI) lights on the left side of the runway and the intended point of landing/aiming point at the beginning of the 1,000 feet Fixed Distance Markers in the center of the runway.

Figure 4

Screenshot of the Animated Forward Chaining Orientation Depicting how a Centered/Level Aircraft Control Yoke Input Maintains the Current Bank and Thus Rate-of-Turn of the Aircraft



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The critically important value of this short, academic orientation to flight cannot be overstated. It was the only traditional classroom ground instruction the STD received prior to training in the Redbird MCX simulator.

Flying STD in the Simulator – Each STD was planned for three, 1-hour simulator sessions, v. the two, 1.5-hour sessions in the first research installment. Ideally these three simulator sessions were to be completed in the same week with the third simulator session immediately preceding flight in an actual aircraft.

Backward Chained STD – The objective of the first session remained to complete Iterations 1 - 7 (Turn-to-Final). During the second simulator session, the remaining iterations were to be completed, with the third simulator session designed as a review, with all of the third session forward chained.

Forward Chained STD – Each STD received three, hour-long simulator sessions during a single week (about every other day, scheduling dependent). The RA provided the instruction during these sessions, with the PI observing and providing feedback, as necessary. Unlike with the previous installments of backwards chaining research, the simulator sessions did not use starting points; instead, each lap in a standard FAA traffic pattern began on the runway at the touchdown point (or where the simulated aircraft had rolled during the previous landing) and concluded with landing back on the runway at the same touchdown point after completing a lap in the pattern.

The RA focused the first session on orienting the STD to the simulator cockpit. The RA performed two landings in the simulator: the first, the STD merely observed while the RA verbally explained and performed the traffic pattern and landing. The second demonstration, the RA had the STD "ghost" the controls (hold the control to feel the inputs but provide no input themselves). The RA gave STD control of the simulator with the RA providing oral and physical inputs. The RA reduced physical flight control inputs as the STD's skill improved. No winds were used on the first simulator session.

Given the time of year and persistent real-world environment wind conditions, the incorporation of exposure to wind was a prudent choice. The second simulator session added a direct headwind of 8 KTS (winds traveling directly down the runway without any crosswind) and focused on improving the STD's skills, while recognizing the effects of a tailwind on Downwind and a headwind on Final Approach. Depending on the STD's progress, the RA stopped physical inputs and relied only on oral assistance. With the core skills being acquired during the first simulator session, the STD could spend more time practicing traffic patterns and landings during the second and third simulator sessions.

The third and final simulator session focused on refining the STD's skills and preparing the STD to fly in the aircraft The RA input the active winds and weather occurring at the airport at the time of the third session. In addition, the RA limited the amount of oral assistance to allow the STD to perform the traffic pattern and landing without assistance. When current weather conditions were either outside of the flight school tolerances or deemed too severe by the PI and RA for an initial STD flight in an actual aircraft, the flight was deferred. In the pair of cases where the environmental conditions warranted this prudence, the RA and PI purposefully delayed the third simulator session so the flight could immediately follow the third simulator session.

Flying STD in Actual Aircraft – For each STD in this second research installment, as soon as the STD completed their third simulation session, the STD was offered the opportunity to experience actual flight in an aircraft equipped identically as the Redbird MCX: a C-172S with G1000 avionics suite. All eight STD flew on the same day or the next day, as their final simulator session with the PI (CFI/CFII/MEI) occupying the right, front seat and a RA acting as a Safety Observer in the rear seat. Due to aircraft availability, one flight was completed in a C-172M equipped with only two front seats (STD 8), thus the Safety Observer could not be included.

Analysis methods – A blend of Grounded Theory/Phenomenology qualitative analysis methods were used to analyze the STD performance, both in the simulator and in-flight. Neither method was utilized fully; rather, appropriate features from both methods were employed to advantage.

Grounded Theory typically assembles a theory from open, axial, and selective coding, identifies categories of information, culls the categories for a singular theme, then builds a theory to explain the occurrence (Creswell, 2007). This research started with a theory (teaching landings first in a simulator would enhance and accelerate flight training for ab-initio STD) which was conceptualized before any of the STD evaluation categories were identified. Principally with experience gained with the first backward chaining STD, four STD performance categories of interest were identified, all were measures of the extent to which the PI was required to intervene for the STD to be able to: a) hold prescribed Heading/Altitude/Airspeed, b) be situationally aware of their aircraft's energy state and other aircraft around them, c) stabilized their final approach to landing, and d) flare and land the aircraft The first three categories are a direct precursor to the fourth, which was the primary research interest – could the STD land the aircraft unassisted? This approach is akin to Grounded Theory being practiced in reverse, i.e., could the pre-assembled theory be grounded in the research execution and observations of the participants' (STD) performance?

Each of these four STD evaluation categories were assessed with a Quality Function Deployment (QFD) approach to quantifying qualitative (subjective) observations, consistent with the methodology espoused by Hauser and Clausing (1988). To effect QFD scoring, two significant collaborative actions were taken by the Principal Investigator and Research Assistant/Safety Observers. First, definitions were written for each of the four categories and for each of the STD ability levels on the QFD scale – see Table 1. The heading/altitude/airspeed tolerances were chosen double of those required for FAA Private Pilot certification. Second, notes taken from the simulator sessions, flights and personal observations were used by the research team to agree on each of the 48 QFD scores assigned in Table 3.

Table 1
QFD STD Evaluation Criteria Applied to Both Simulator and In-flight Performance

	Required PI Intervention for STD to:			
	Hold HDG/ALT/TAS	Be Situationally Aware	Stabilize Final Approach	Flare/Land
QFD-based Definitions	HDG: +/- 20° ALT: +/- 200' TAS: +/- 10 KTS	How aware is the STD of their aircraft's position and energy state? Are they able to make appropriate adjustments without PI provocation? Are they aware of other aircraft around them?	Is the STD able to balance, with out PI provocation, Altitude, Glide Path, Power (RPM) and position to achieve a stabilized final approach to land?	Can the STD judge for themselves when it is appropriate to transition from approach (nose-down) aircraft pitch attitude to a flare and land (nose-up) pitch attitude? Can the STD accomplish this transition, smoothly, without over correcting and without PI intervention?
0 (No ability)	STD unable to hold HDG/ALT/TAS tolerances, constant CFI intervention required.	Other than their immediate forward focus, STD unable to process any additional situational information.	STD unable to stabilize HDG/Glide path/TAS/RPM; constant, divergent changes in more than one parameter, requiring immediate CFI intervention.	STD unable to transition aircraft attitude from approach to flare unassisted, and unable to land aircraft unassisted.
1 (Very limited ability)	STD unable to hold one or two of HDG/ALT/TAS tolerances, constant CFI intervention required.	STD able to process current position in traffic pattern, but unable to recognize off-track deviations.	STD able to stabilize only one of: HDG/Glide path/TAS/RPM; constant, divergent changes in at least one parameter, requiring immediate CFI intervention.	STD required CFI assistance to transition aircraft attitude from approach to flare, and required CFI assistance to land aircraft.
3 (Acceptable ability)	STD able to hold HDG/ALT/TAS tolerances with occasional CFI intervention required.	STD able to process current v. desired position in traffic pattern and make appropriate corrections to desired track.	STD able to stabilize two or three of: HDG/Glide path/TAS/RPM; changes in one parameter, requiring immediate CFI intervention.	STD able to transition aircraft attitude from approach to flare, but required CFI assistance to land aircraft.
9 (Exceptional ability)	STD able to hold HDG/ALT/TAS tolerances, with no CFI intervention required.	STD able to process current v. desired position in traffic pattern, make appropriate corrections, and is aware of other aircraft traffic.	STD able to stabilize HDG/Glide path/TAS/RPM; no CFI intervention required.	STD able to transition aircraft attitude from approach to flare and land aircraft without CFI assistance.

The Phenomenology application to this research revolved around the researchers placing the STD in a new-to-them situation, asking the STD to experience phenomena, which the researchers themselves had never experienced – the PI and all the RAs had learned to fly in the traditional, forward-chained manner and specifically were not taught to land the aircraft on their first flight lesson. As Creswell (p. 78, 2007) so aptly states, we were interested in, "Understanding the essence of the experience", and "Studying several individuals that have shared the experience". Observations, questions asked of the STD, and STD feedback were used to assess the situation/phenomena they experienced.

Neither Grounded Theory nor Phenomenology were applied in their pure qualitative analysis methods sense in this research; rather, components of both methods were used to structure and evaluate STD actions and performance.

Results

This section presents the second round of four backward chained STD results and their feedback, the four forward chained STD results and their feedback, the quantitative analysis of all STD performance, and recognition of study limitations.

Backward Chaining Results – Table 2 indicates on the left the four STD who completed the second installment of backward chaining simulation (numbered as Pilots, 5 - 8) the dates, start/stop and cumulative time spent in the simulator, and the each iterations' number of occurrences. The red cell triangles contain PI notes applicable to the particular date and student's performance.

Table 2

Backward Chaining Simulation Experience Results for second installment of four STD

			1	2	3	4	5	6	7	8	9	10	11	12	13	14				
		Iteration	Just Prior to Touchdown	Flare	Ground Effect	Entering Ground Effect	Short Final	Final Approach	Turn-to-Final	Turn-to-Base	Abeam Intended Point of Landing	Turn-to-Downwind	Top of Climb (TOC)	Turn-to-Crosswind	Upwind Climb	Take-Off	Total Simulated Landings			
		Alt (AGL)	4	8	16	32	64	200	400	700	↓ 700	1,000	1,000	↑ 700	↑	0				
		Time to Touchdown (sec)	1	2	3	6	12	37	76	121	169	245	269	284	353	363				
Date	Pilot	Start																Stop	Length	Cumulative
2-Sep-21		11:07	3	3	3	2	4	6	3									12:35	1:29	
3-Sep-21	5	15:15							5		2	1				1	39	16:49	1:34	3:43
7-Sep-21		16:20														6		17:01	0:41	
7-Sep-21																			1.0	
3-Sep-21		2:22	3	3	2	3	2											2:57	0:35	
7-Sep-21	6	11:37					3	5	5								36	12:40	1:03	3:01
9-Sep-21		10:45									4			1		5		11:58	1:13	
9-Sep-21																			1.6	
9-Sep-21		13:21	1	1	2	3	2	4	3		3	1				2		14:58	1:27	
10-Sep-21	7	14:13														5	27	14:41	0:28	1:55
11-Sep-21																			0.7	
28-Sep-21		17:30	2	1	1	5	2	2										18:22	0:52	
30-Sep-21	8	16:47						2	3		2			1			28	17:40	0:57	2:42
5-Oct-21		17:05														7		17:57	0:52	
6-Oct-21																			0.7	

Averages:	33	1.0	2+55
Total iterations	130		
Total different iterations completed	45		
Average number of individual iterations repeated:	2.89		

Average number of iteration repeats (3), total iterations (33), total time in simulation (2 hr. + 55 min), and flight time (0.85 hr.) in the second research installment compared favorably with first research installment averages of 3, 32, 2hr + 37 min, 0.85, respectively. The documented (1.6 hr.) flight time for STD 2 in this second research installment included a 0.6-hour (two-way) transit to a satellite airport which was necessary to avoid home airport traffic pattern saturation. Since it was not material to this research, the 0.6-hour transit time was removed from the total incurred flight time to arrive at an average flight time of 0.85 ((1.0+1.6-0.6+0.7+0.7)/4 = 0.85) v. the mathematical average of 1.0 shown in the table.

Also observable in Table 2, in addition to the planned elimination of iterations 11 and 13, were the elimination of iteration 8 and the effective elimination of iterations 10 and 12. Once the STD had mastered landing from iteration start point 9 (Abeam the Intended Point of Landing), they were essentially vaulted to iteration 14 (Take-Off) and flying the traffic pattern in a forward chained manner.

Figure 5 shows the collection of solicited, unedited feedback from the pair of RAs/Safety Observers, and the four STDs involved in the second installment of backward chaining.

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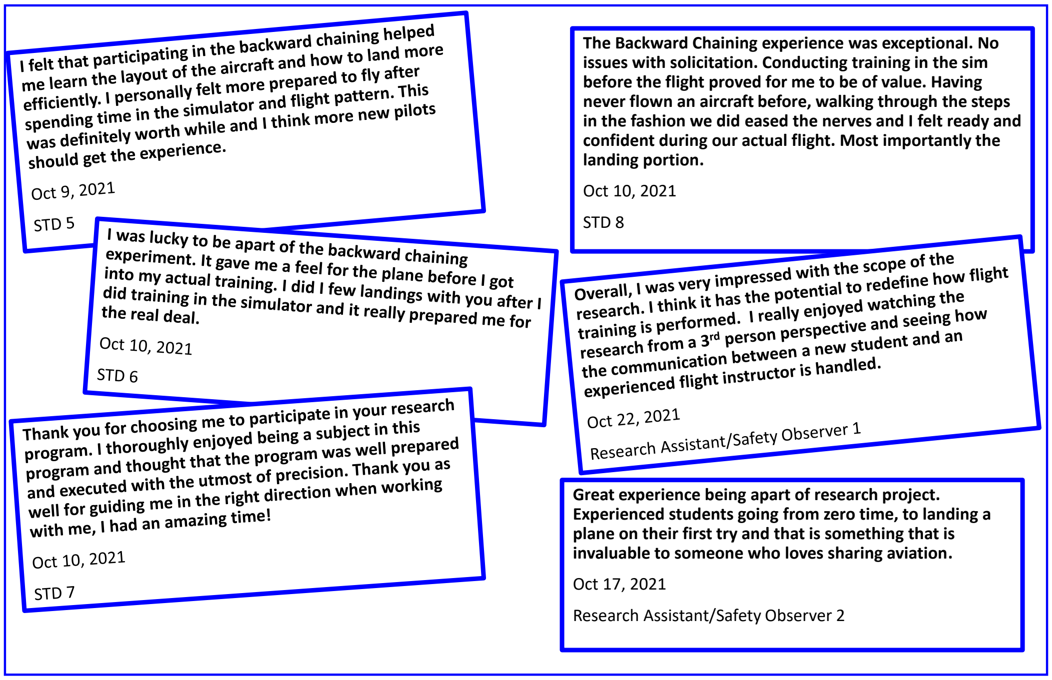
Figure 5

Unedited Comments from Participating RAs and STDs in Second Backward Chaining Research Installment



Forward Chaining - and - All Results – Figure 6 shows the collection of solicited, unedited feedback from the four forward chained STDs.

Figure 6

Unedited Comments from Participating STDs in the Forward Chaining Research

Overall, I absolutely loved my experience in flight training with the research team. From the start I felt as if I was treated in a professional manner, and the team was truly looking to teach me as much as they could in the time we had together. Both Dr. Vance and Brendan provided helpful feedback to me during flight sim hours that helped me to retrain how I understood planes were flown from my engineering background. I felt that I learned a lot about how a pilot treats a plane and how that differs from how engineers design planes. The coolest part was to see some of the things we were talking about in class like Vy and other performance characteristics actually being used. The research team treated me with the utmost respect and safely allowed me to learn in an effective manner. I still can't believe that in one week I went from never having touched an actual flight simulator to landing and taking off a plane.

The only thing even remotely close to a critique that I have is that now I think I've caught the piloting bug and am going to have to figure out how I can get my own private pilots license. I didn't really need another hobby, but I guess I've found one. Thanks again for the opportunity! It was incredible and I feel honored to have gotten this chance!

Jun 12, 2022

STD 9

I was certainly treated professionally and courteously throughout my flight instruction with you all. I was surprised by how I intuitively learned the connection between power, controls, and actual aircraft maneuvering. From an engineer's perspective, it was fascinating, for example, to see the plane dip with an aileron input for turns and compensating by inputting some elevator as well. I was surprised by (other than a couple of hiccups by inputting controls in the wrong direction) by how intuitive the controls for an aircraft were, given the difference between controlling an aircraft and any other kind of vehicle that we're used to. I was also surprised by how ready I was to fly in a real aircraft given the short amount of time that we had to prepare. It was comfortable and at no point (except when I had to throw up) did I feel like I was out of control of the airplane. Thank you for handling that incident with as much grace as it was possible to and helping me clean up afterwards. That probably wasn't too pleasant.

I was grateful for the respect and encouragement I received from both you and Brendan during the learning process. I was also thankful for your ability to reschedule when the conditions weren't right for flying and I hope that it didn't cause any complications with the results of the research. I was also frankly grateful to have this experience without having to pay for it, so thank you to you and to OSU for that. I would say that the experience was enjoyable, memorable, and empowering. I feel like I've been given the confidence to try for a private pilot's license in the future if I can afford it.

I don't know whether this is possible, but it seems like the only thing that may make the experience of transitioning from simulator to airplane easier is if the resistance on the inputs to the aircraft is similar between the aircraft and the simulator. It seems like it's something that could be possible, and otherwise I recognize that there's only so much that you can do about the fidelity of a simulator.

Jun 13, 2022

STD 11

Thanks again for letting me participate in the research. This was one of the best experiences in my college career and I'll always remember it. I knew nothing about flying and very little about planes going into the first simulator session and you and Brendan's patience, positive attitudes, and knowledge helped calm me and in turn give me confidence and ability to fly. Because of this, I learned a whole lot about flying (the basic maneuvering, steering, some language, etc.) and have a newfound interest in it. Again, this was an awesome experience, and I cannot thank you all enough for teaching me and letting me be in the research group.

Jun 11, 2022

STD 12

I really enjoyed learning how to fly through this research! Dr. Vance and Brendan were courteous and patient with me as they taught me how to fly. One thing I didn't realize before getting in the sim was just how many things there were to think about at once. Trying to focus on several things at once was pretty hard for me. That said, I appreciated the way that through the three simulations I was gradually taught different things; I think that helped me be less overwhelmed. Thanks for letting me participate in this research, and please let me know if you need anything else from me.

Jun 15, 2022

STD 10

Table 3 shows the forward chaining results for the four STD sampled in the lower section, and a summary of all eight backward chained STD in the upper section. The display formats for both sections are the same and include, left-to-right columns for: STD, event date/objective/FAA traffic pattern iteration points used and time (tenths of hours), presence of a RA/Safety Observer, total time in the simulator (AATD), winds (either simulated or actual, as appropriate), the four analyzed STD performance categories, number of landings accomplished on respective date, and total number of simulator (AATD) landings.

At the bottom of Table 3 are the statistical tallies (Mean, Standard Deviation, p-value, and statistical significance) between the backward and forward chained STD calculated with a Welch's t-test, two sample/unequal variance at $\alpha = 0.05$. Computed Means and Standard Deviations are for the flights only and do not include the AATD data. The AATD data is shown for completeness.

Table 3 illustrates there are no material differences between the two groups of four STD who were backward chained (STD 1 - 4 v. STD 5 - 8). The (unanticipated) different Cessna models, or instrumentation (the M was/is a steam-gauge), nor the differing wind conditions experienced by the backward chained STD materially affected the research outcomes.

The column labeled “FAA Traffic Pattern Iteration Points” shows that for the flights in the actual aircraft, all 12 STD were “Forward Chained” – that is because the only way to actually fly an aircraft from Take-Off around a traffic pattern to Landing is in a forward chained sequence. To further elaborate on this point, note that the for the eight backward chained STD, the respective iteration start points are noted; but, for the four forward chained STD, the iteration start point is always #14 – the initiation of the Take-Off roll.

Table 3

Summary Results for the 12 Participating STD: 1-8 Backward Chained, 9-12 Forward Chained

									Required PI Intervention for STD to:					
STD Pilot	Date	Device	Objective	FAA Traffic Pattern Iteration Points	Time	Safety Observer Present?	Total Sim Time	Winds Headwind = < +/- 10° Slight Quartering = > 10°, but < 25° Quartering = > 25°, but < 45°	Hold HDG/ALT/AS	Be Situationally Aware	Stabilize Final Approach	Flare/Land	# STD Landings	Total # AATD Landings
Backward Chaining														
1	3-May-19	AATD	Orientation	1-8	1.0		2.7	n/a	0	1	1	3	12	25
	6-May-19	AATD	Proficiency	7-12, 14	1.2			n/a	1	1	3	3	10	
	8-May-19	AATD	Prepare to Fly	14	0.5			n/a	3	1	3	3	3	
	9-May-19	C-172R	3 circuits in FAA Traffic Pattern	Forward Chained	1.0	Yes		Light/Variable	3	3	9	3	3	
2	12-Dec-19	AATD	Orientation	1-8	1.2		2.4	n/a	1	1	3	3	25	35
	13-Dec-19	AATD	Prepare to Fly	8-10, 12, 14	1.2			n/a	3	1	9	3	10	
	13-Dec-19	C-172R	3 circuits in FAA Traffic Pattern	Forward Chained	0.7	No		Light/Variable	9	3	9	3	3	
3	13-Dec-19	AATD	Orientation	1-8	1.4		2.7	n/a	3	3	3	3	26	34
	16-Dec-19	AATD	Prepare to Fly	8-10, 12, 14	1.3			n/a	9	3	3	3	8	
	17-Dec-19	C-172S	3 circuits in FAA Traffic Pattern	Forward Chained	0.7	Yes		Left Quartering 5-6 KTS	9	3	3	3	3	
4	14-Jan-20	AATD	Orientation	1-8	1.3		2.5	n/a	1	1	3	3	22	34
	16-Jan-20	AATD	Prepare to Fly	8-10, 12, 14	1.2			n/a	3	3	3	3	12	
	21-Jan	C-172S	3 circuits in FAA Traffic Pattern	Forward Chained	0.9	No		Right Quartering 8-10 KTS	9	9	9	3	3	
5	2-Sep-22	AATD	Orientation	1-7	1.5		3.8	n/a	1	1	1	1	24	39
	3-Sep-21	AATD	Proficiency	7, 9, 10, 14	1.6			n/a	1	3	9	3	9	
	7-Sep-21	AATD	Prepare to Fly	14	0.7			n/a	9	3	9	3	6	
	7-Sep-21	C-172R	3 circuits in FAA Traffic Pattern	Forward Chained	1.0	Yes		Right Quartering 10 KTS	9	3	9	3	4	
6	3-Sep-21	AATD	Orientation	1-5	0.6		2.8	n/a	1	3	3	3	13	36
	7-Sep-21	AATD	Proficiency	5-7	1.0			n/a	0	1	1	0	13	
	9-Sep-21	AATD	Prepare to Fly	9, 12, 14	1.2			n/a	3	1	1	1	10	
	9-Sep-21	C-172S	3 circuits in FAA Traffic Pattern	Forward Chained	1.6	Yes		Slight Right Quartering 10 KTS	1	1	1	1	2	
7	9-Sep-21	AATD	Orientation	1-7, 8, 9, 14	1.5		2.0	n/a	3	3	3	3	22	27
	10-Sep-21	AATD	Prepare to Fly	14	0.5			n/a	9	3	9	9	5	
	11-Sep-21	C-172S	3 circuits in FAA Traffic Pattern	Forward Chained	0.7	Yes		Headwind 15 KTS	9	3	9	9	1	
8	28-Sep-21	AATD	Orientation	1-5	0.9		2.7	n/a	0	0	1	3	13	28
	30-Sep-21	AATD	Proficiency	5-7	0.9			n/a	1	1	3	3	8	
	5-Oct-21	AATD	Prepare to Fly	9, 12, 14	0.9			n/a	3	3	3	3	7	
	6-Oct-21	C-172M	3 circuits in FAA Traffic Pattern	Forward Chained	0.7	No		Right Quartering 7 KTS	9	3	9	3	3	
				averages:	0.84		2.7		7.3	3.5	7.3	3.5		32
				standard deviation	0.14		0.48		3.07	2.18	3.07	2.18		4.63
Forward Chaining														
9	28-Mar-22	AATD	Orientation	14	0.9		2.8	n/a	0	1	1	3	4	21
	30-Mar-22	AATD	Proficiency	14	0.9			Headwind - 8 KTS	1	1	3	3	8	
	1-Apr-22	AATD	Prepare to Fly	14	1.0			Slight Left Quartering 10 KTS/Gust 18 KTS	3	3	3	3	9	
	1-Apr-22	C-172S	3 circuits in FAA Traffic Pattern	Forward Chained	0.9	Yes		Slight Left Quartering 10 KTS/Gust 18 KTS	9	3	9	3	3	
10	4-Apr-22	AATD	Orientation	14	0.9		2.8	n/a	0	0	0	1	6	20
	6-Apr-22	AATD	Proficiency	14	1.0			Headwind - 6 KTS	1	1	1	0	7	
	11-Apr-22	AATD	Prepare to Fly	14	0.9			Right Quartering 14 KTS/Gust 20 KTS	3	1	1	0	7	
	11-Apr-22	C-172S	3 circuits in FAA Traffic Pattern	Forward Chained	0.6	Yes		Right Quartering 14 KTS/Gust 20 KTS	3	1	1	1	1	
11	12-Apr-22	AATD	Orientation	14	1.0		2.9	n/a	3	1	1	3	5	19
	14-Apr-22	AATD	Proficiency	14	0.8			Headwind - 6 KTS	3	1	3	3	7	
	19-Apr-22	AATD	Prepare to Fly	14	1.1			Sight Left Quartering 18 KTS/Gust 26 KTS	3	1	3	0	7	
	19-Apr-22	C-172R	3 circuits in FAA Traffic Pattern	Forward Chained	0.8	Yes		Slight Left Quartering 18 KTS/Gust 26 KTS	9	3	9	3	2	
12	18-Apr-22	AATD	Orientation	14	0.9		2.8	n/a	1	1	1	1	4	17
	20-Apr-22	AATD	Proficiency	14	1.0			Headwind - 8 KTS	3	1	3	3	5	
	21-Apr-22	AATD	Prepare to Fly	14	0.9			Left Quartering 20 KTS/Gust 25 KTS	3	3	3	3	8	
	21-Apr-22	C-172R	3 circuits in FAA Traffic Pattern	Forward Chained	0.9	Yes		Left Quartering 20 KTS/Gust 25 KTS	9	3	9	3	3	
				averages:	0.80		2.8		7.5	2.5	7.0	2.5		19
				standard deviation	0.12		0.04		2.60	0.87	3.46	0.87		1.48
				for Welch's t-test, two-sample, unequal variances, is p < .05?	0.623		0.576		0.909	0.285	0.888	0.285		0.000
				Statistically significant difference (α = .05)?	No		No		No	Yes	No	Yes		Yes

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Recognition of Study Limitations – The following are self-recognized potential limitations of this research:

- ***Sample size*** – A sampling of n = 12 STD is not a large sample and limits the ability to draw binding conclusions. Note that four of the backward chained STD's data is from the prior 2021 published study installment; the separation of time and slight differences in methodology applied to the four more recent backward chained STD in this study installment, completed in 2022, could be influencing results. Also note in the 2022 study installment, a total of eight backward chained STD are compared with four forward chained STD. The dissimilar sample sizes of eight backward chained STD v. four forward chained STD could also be influencing results.
- ***Redbird MCX AATD fidelity*** – While not optimized with up-to-date Visual Meteorological Condition or terrain graphics, the simulator was adequate for the research tasks in a visual-based study. The airspeed upon simulator un-freeze, however, was an irritant. Even though programmed in the starting conditions, the requested airspeed was not instantaneously available at simulation release from freeze. Airspeed was restored almost instantaneously, but this delay always caused an immediate, nose-down, pitching moment from which the STD would have to recover to the desired pitch attitude for the leg. This nose-down pitching moment at simulation unfreeze devalued iterations 1-4 and was a consistent distraction in both backward chaining research installments. Not until iteration 5, with 12 seconds of flight time remaining was there sufficient opportunity for the STD to affect a recovery. Iteration 6, with 37 seconds of flight time remaining provided even more opportunity and from this point forward in the research, this simulator limitation became less of a distracting issue.
- ***STD major/motivations*** – The first eight backward chained STD were all Professional Pilot majors with the expectation of starting formal, curriculum flight training eminently and were eager to participate in the research because of the early flight training exposure they would be receiving at no financial expense. The four forward chained STD however were not Professional Pilot majors; rather, they were all Engineering, three Aerospace/Mechanical and one Computer, majors; and, with no propensity, nor plans, to receive flight training in the immediate future.
- ***Environmental conditions, in particular, wind*** – There is a significant disparity evident in Table 3 in the general wind conditions between the backward and forward chained STD. It is not so much the wind direction or velocity that is the issue, rather it is the gusts. Gusts, by definition, are unpredictable; whereas a pilot can be apprised in advance of steady-state winds and prudently apply flight control corrections in advance; this simply cannot be done for gusts. Gusts must be reacted to, correctly and quickly, to effect safe, smooth transition-to-flight in Take-Off, and more importantly transition-from-flight when landing. The most egregious situation occurs

when gusts are not aligned with the landing direction, as was experienced by STD 10 and 12. The time of year was principally responsible for the consistent difference in experienced winds. The entire forward chained segment of this research would have needed to be deferred to seek lessor wind/gust velocities; however, based on the impeding end of the semester and STD availability, deferring was reluctantly not a viable logistic research option.

Discussion

This section includes a comparison between backward and forward chained STD performance, individual STD commentary, conclusions, and recommendations for further research.

Overall observations between backward and forward chained STD – referencing from Table 3, left-to-right:

- ***Average flight time*** – (neglecting the 0.6 hr. transit previously discussed for STD 6) of 0.84 hrs. v. 0.80 hrs. respectively was not a statistically significant difference.
- ***Average simulation time*** – 2.7 v. 2.8 hrs. respectively, was not a statistically significant difference; there were two outliers, one high (STD 5, 3.8 hrs.) and one low (STD 7, 2.0 hrs.).
- ***Environmental conditions*** – higher wind velocities, and especially wind gusts, were prevalent for all four forward chained STD in the spring semester v. fall semester for the backward chained STD. No gusts were documented for any backward chained STD.
- ***QFD Evaluation of required PI intervention in STD performance categories –***
    - **HDG/ALT/TAS.** 7.3 v 7.5 respectively was not a statistically significant difference; generally by the time the STD flew the aircraft, their ability to hold heading, altitude and airspeed (within deviations less than twice the FAA Private Pilot certification tolerances) was sufficient to not require PI intervention and was independent of the type of simulation received.
    - **Situational Awareness.** 3.5 v. 2.5 respectively was a statistically significant difference; Observe that STD 4's score of "9" is driving this difference, he was the *only* STD to recognize and pay attention to other aircraft in the pattern. Effectively then, STD 4 is an outliner; remove his score and there is no statistically significant difference between the backward and forward chained STD.
    - **Stabilize Final Approach**. 7.3 v 7.0 respectively was not a statistically significant difference; as would be reasonable to expect, STD's performance with HDG/ALT/TAS is directly relatable to and influential in their ability to minimize deviations in glide path and correct them when they do occur.

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- **Flare/Land**. 3.5 v. 2.5 respectively was a statistically significant difference; here again however, the statistical interpretation could be misleading, if outliers are removed, there is no statistically significant difference between the backward and forward chained STD's ability to land the aircraft Nine of the 12 STD were able to consistently land the aircraft with (minimal) nose-up pitch assistance from the PI. STD 7's strong solo performance (albeit for only one landing) and STD 12's strong solo performance in challenging wind conditions contrasts with STD 6 and 10 who had consistent difficulty with the task of actually landing. The level of PI intervention was consistently more significant with the forward chained STD than with the backward chained.

- ***Landings in aircraft*** – In all cases except one (STD 7), the PI, in addition to requesting the STD do so also, exerted slight additional back pressure on the yoke to prevent, at a minimum, a three-point landing.

The four forward chained STDs required significantly more assistance during the transition from Final Approach to Flare/Landing the aircraft than those who learned using backwards chaining. PI intervention was required to stabilize the aircraft at an appropriate nose-high attitude for touchdown.

Not all STD completed the desired three landings in actual aircraft:

- STD 5 completed four landings because the PI simply forgot to demonstrate the first circuit in the pattern and instead allowed the STD the opportunity to fly.
- STD 6 required a PI-initiated Go-Around on second landing (amplification in following sub-section); STD completed two landings.
- STD 7 self-elected to terminate flight after first landing (amplification in following sub-section); STD completed one landing
- STD10 required a PI-initiated Go-Around on second landing, and due to a second unstabilized approach, PI elected to complete third landing; STD completed one landing.
- STD 11 became physically ill (motion sickness) during the transition to flare in his last landing, requiring PI to land; STD completed two landings.

- ***Landings in simulator*** – average of 32 v. 19 respectively was a statistically significant difference. This difference in landings exposure is likely the principal reason the backward chained STD required less PI assistance transitioning from Final Approach to Flare and Landing; they simply had substantially more landings exposure in the simulator prior to flight in the aircraft

Individual STD commentary –

STDs 5 and 6 experienced a learning plateau at iteration 7, meaning the STDs were struggling to successfully and smoothly execute the Base-to-Final turn and reestablish themselves on the final approach corridor in a stabilized, aligned with the runway, descent. To break this barrier, the PI decided to vault ahead to iteration 9

(Abeam the Intended Point of Landing). To accomplish a landing, this iteration requires two 90°course changes and necessitated the STD reestablish a visual sight picture with the runway on Base leg as the 150° Redbird MCX field-of-view removed the runway touchdown zone as soon as the simulation progressed Downwind beyond the abeam point. The rationale for this change was to allow the STD more time setting up a controlled descent prior to the need to execute a 90° turn. This strategy worked well, it allowed the STDs the opportunity to execute two 90° turns, correct the heading after the first turn to Base leg thereby providing an immediate reference on how to realign with a desired course. The learning plateau was broken and this approach of skipping iteration 8 was applied successfully with last two STDs.

Once the backward chained STDs had been exposed to and successfully accomplished iteration 7 (Turn-to-Final), and had advanced to iteration 9 (Abeam Intended Point of Landing), with four singular exceptions, they then were advanced directly to iteration 14 (Take-Off). Iteration 14 is no longer a backward chained activity but a complete forward chained, traditional pattern sequence.

STD 7's performance was a positive outlier in this research – the assimilation of flight principals and aircraft control was so strong that the STD progressed through the entire series of backward chained iterations in one simulator session. Planned simulator sessions 1 and 2 were accomplished in the first session. The planned third simulator session was accomplished as the second session, and even this was abbreviated to 28 min.

STD 7 and 8 from the second research installment (and STD 1 from the first research installment) required ~ ⅓ fewer total simulator iterations than their peers. All were strong, smooth pilots – which is noteworthy as this was their first actual experience piloting either a simulator or real aircraft.

There were two unexpected developments in this research installment that warrant discussion:

1) ***STD 6's hazardous attitude of resignation*** – STD 6's first simulator session was strong. He was a quick study with strong uptake in an abbreviated time slot due to scheduling – he was, however, the only respondent to not advance to iteration 7 on their first simulation session.

   Simulator session 2 revealed difficulty mitigating unwanted bank, and repeatedly accepting deviations in altitude, airspeed, bank, and position without purposeful correction. When deviations occurred, and no corrective action was being taken, the PI was required to point out the deviations to the STD. This was the first time in the PI's career to witness the FAA hazardous attitude of resignation. Simulator session two concluded with STD plateaued at Iteration 7.

   The PI elected to start simulator session three by jumping to Iteration 9 and emphasizing the value of maintaining, and how to maintain, 65 KIAS on Final Approach - with positive result. Pattern circuits were completed satisfactorily but not without continuous prompting from PI on correct actions and flight parameters, particularly altitude and final approach

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alignment. This was inconsistent with the STD's strong, first simulator experience.

The immediately following flight required repositioning to a satellite airport to escape the primary airport traffic pattern intensity. STD 6's resignation attitude was prevalent right from the start of taxi; deviations incurred the moment we left the chocks and were not corrected without PI prompting. This was, reluctantly, a precursor to the entire flight. STD 6's aircraft control was consistently weak and without recognition of repeated exceedance of proper airspeed and pitch attitude. Landings all required PI intervention at various degrees – the second STD landing attempt resulted in a PI-initiated Go-Around during the flare to land as at about 10-15 feet of altitude the aircraft incurred a gust and was allowed to suddenly deviate to a substantial right side-slip, nose-high attitude, with the airspeed in rapid decay, and departing the right side of the runway. Not knowing differently, the STD was going to allow the aircraft to contact the surface in this attitude.

2) ***STD 7's "refusal" to continue*** – On the contrary to STD 6's hazardous attitude of resignation, STD 7 demonstrated amazing, seemingly innate uptake of basic flight principles in the simulator – the balance of rudder with aileron input was especially impressive. His ability to judge proper glide path and make appropriate pitch and then throttle adjustments was remarkable!

   In the actual aircraft, save for taxi, STD 7 was an extremely strong and smooth respondent in handling winds 15G21, 10° off runway heading. However, after an incredibly smooth transition to flare and first landing, STD 7 over-corrected with rudders on rollout to regain centerline to the point that student took hands off yoke and declared, "You got it!" STD appeared to both the PI and rear seat RA/Safety Observer a combination of flustered, embarrassed, and angry-at-self. Somewhat curiously and disappointingly, only because up to that point he had done so well, STD 7 refused PI's offer to complete two more circuits in the pattern.

Conclusions/Recommendations for Further Study

How Grounded was our Theory? – The positive attitudes and comments shown in Figures 5 and 6, and those shown in Figure 7 (Vance, et al. 2021) give tangible support to the theory that teaching landings first in a simulator could enhance and accelerate flight training for ab-initio STD. Longitudinally tracking each STD's progress in a follow-on, controlled experiment would be a proper way to show this theory is valid.

What Phenomenon did the 12 STD experience? – What was the essence of the STD experiences? When aggregated, comments illustrated in Vance et al. (2021), Figure 7 and here in Figures 5 and 6 show a consistently positive experience. Excerpted comments include:

- "The backwards chaining research was a very motivating method of training…" (STD 1)
- "…research put me one step ahead of other students…" (STD 2)
- "Once I took what I had learned from the simulation and transferred it to an actual aircraft, I felt very comfortable and confident in my ability." (STD 4)
- "This was definitely worthwhile and I think more new pilots should get the experience." (STD 5)
- "I was lucky to be a part of the backward chaining experiment." (STD 6)
- "Thank you as well for guiding me in the right direction when working with me, I had an amazing time!" (STD 7)
- "The Backward Chaining experience was exceptional." (STD 8)
- "I still can't believe that in one week I went from never having touched an actual flight simulator to landing and taking off a plane." (STD 9)
- "I really enjoyed learning how to fly through this research! …I appreciated the way that through the three simulations I was gradually taught different things; I think that helped me be less overwhelmed." (STD 10)
- "I was also surprised by how ready I was to fly in a real aircraft given the short amount of time that we had to prepare. It was comfortable and at no point (except when I had to throw up) did I feel like I was out of control of the airplane." (STD 11)
- "Again, this was an awesome experience, and I cannot thank you all enough for teaching me and letting me be in the research group." (STD 12)

The researchers observed that for the participants, the essence of their STD experience is they were afforded and opportunity to do something they knew they wanted to do, but did not necessarily believe it possible so quickly, and they enjoyed the experience.

Research Response/Comments to RQ1 and RQ2 –

- **RQ1** – If a STD with no prior flight-training experience is first taught to land the aircraft in a simulator via a backward chaining approach, will this permit them to complete unassisted, three circuits in a standard FAA airport traffic pattern in an actual aircraft?

Response to RQ1) – While overall research results are encouraging, and our answer to RQ1 is – yes it is possible to teach a STD, with no prior flight-training experience, to land the aircraft in a simulator first, via a backward chaining approach, permitting them to complete unassisted, three circuits in a standard FAA airport traffic pattern in an actual aircraft

The entirety of both backward chaining research installment results discussed in this paper should be appropriately viewed as a "think piece" of what may be possible in future flight training. The larger number of now eight sampled STD is an indicator but still not a statistically significant set of results. Based anecdotally on the comments received in both research installments, focusing flight training first on the historical impediment to solo (i.e., learning to land the aircraft) could be a significant, positive STD confidence builder.

- **RQ2** – Is there a perceptible difference in ability to complete unassisted, three circuits in a standard FAA airport traffic pattern in an actual aircraft if the STD is first taught to land the aircraft in a simulator, with a forward chaining approach instead of a backward chaining approach?

Response to RQ 2) – It is both appropriate and important to recognize and acknowledge that simulation (forward or backward chained) may be more significant for an ab-initio flight student than which method is employed. Determining whether forward or backward chaining can be distinguished as preferable for pre-solo, ab-initio flight students is an open area for further research. Research conducted on the differences/distinctions between forward and backward chaining does not conclusively favor one method over the other. Mulgund (1995), Sharma et al. (2012), and Al-Ajlan (2015) acknowledge that backward chaining focuses more strongly on the goal, early – which the employed flight instruction in this research methodology replicates since it allows substantially more opportunity for the STD to land the aircraft (the goal) in the same period of simulator time than a forward chained approach would allow.

Our very general conclusion, based on our observations and analysis of the STD performance is if the desire is to teach landings first to ab-initio pilots, chose the backward chaining approach as it allows significantly more landings exposure in the same amount of instruction time.

Future Research – It is the PI's observation that enthusiasm of flight program leadership to support out-of-the-box flight training techniques is inversely proportional to the commercial aviation hiring climate. When hiring is strong, the motivation to innovate and invest in change is diminished in favor of production output/quantity of new pilots. Could backward (or, forward) chaining simulation exposure make a difference in time-to-solo? Would this simulation-prior-to-flight-training-in-an-actual-aircraft approach be an overall attractiveness to a flight program/a potential differentiator? In a slower hiring environment, these qualities may be more attractive in gaining program endorsement and momentum.

If your institution/flight school is interested in trying the backward chaining, pre-solo techniques this exploratory research has presented, the authors would be privileged to share any of the discussed methodological steps and planning files as well as answer your questions.

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