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BLUE-SKY Learning: The Wolverine CubeSat Development Team (2015-2020)

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Abstract

The Wolverine CubeSat Development Team (WCDT) employs a 'BLUE-SKY Learning' philosophy. Young students have the potential and resources to accomplish remarkable technical feats - even launching their own spacecraft. The WCDT, initially located at the Weiss School in Palm Beach Gardens, Florida remains the only middle school (grades 6th-8th) program nationwide to have successfully launched a CubeSat mission with NASA's CubeSat Launch Initiative (CSLI). Following the launch in 2018 of their first CubeSat, the WeissSat-1, they were selected for a second satellite, the CapSat-1 by NASA in 2019. It is expected to launch in 2021. The WCDT leverages the excitement of young people towards aerospace and the accessibility of CubeSats to engage the new generation STEM workforce. While in the past only nations could build and deploy spacecraft, today CubeSats, in conjunction with NASA's CSLI, represent a pathway for a middle and high schools to put their student-built satellites into space. The uniqueness of the aerospace experience is ideally suited for gifted students and teachers. The small nanosatellite form factor is approximately 10 cubic centimeters in volume and originally designed to train engineering students through the life cycle of a satellite (design, assembly, testing, and flight) while in college. With the emergence of lower cost access to space, the miniaturization of electronics, and the standardization of the form factor, CubeSats represent a tremendous learning tool to incorporate both hard and soft skills. Students are immersed in the convergent and real-world themes of systems engineering, project management, and authentic research, all while applying maximum creativity and critical thinking to earn or win flight opportunities to space. Students who develop CubeSats are required to both specialize individually and collaboratively to integrate a spacecraft payload and bus, successfully test the vehicle to stringent certification criteria, and are encouraged to interact with numerous government agencies such as Congress and NASA. We live at the precise time in humankind's history that large numbers of people now have access to low cost technology, infinite information, and access to capital resources sufficient to accomplish extraordinary, or even 'BLUE-SKY' goals. The WCDT program has shown that if properly equipped educators may guide and inspire their young students, even as young as 10-12 year olds, to develop their own authentic aerospace program.

Keywords: CubeSat, BLUE-SKY Learning, Coopetition, Game Theory, Growth-Mindset, Design-Based Research

Acronyms/Abbreviations

Augmented Reality/Virtual Reality (AR/VR), CubeSat Launch Initiative (CSLI), Electrical Power System (EPS), Socio-scientific Issue (SSI), Science, Technology, Engineering, Math (STEM), Systems Tool Kit (STK), Wolverine/Wolfpack CubeSat Development Teams (WCDT).

1. Introduction

'BLUE SKY' research refers to research done by for-profit corporate entities without a clear product or immediately monetizable application [1]. While in the 1900's Bell Labs and IBM were well known for the quality and quantity of basic research, today the increased pressure for maximizing stockholder returns has discouraged companies from doing likewise. Google X may be the only current company engaging in BLUE SKY research. Similarly, BLUE SKY science' focuses on the 'curiosity driven pursuit' of new knowledge through basic research, and many see this fundamental work as the 'crucial first step to innovation.' MIT theoretical physicist Frank Wilczek said, "applied research is exploring the continents you know, whereas basic research is setting off in a ship and seeing where you get… so it's much more long-term, it's riskier and it doesn't always pay dividends" [2].

A similar "BLUE-SKY Learning" philosophy is employed by this lead author to engage and inspire team members. From the students' perspectives, the idea of boldly accepting a challenge that is seemingly beyond their ability is the central core of BLUE-SKY Learning. The 6^{th}-8^{th} grade Wolverine CubeSat Development Team engages in an academic journey to accomplish what was previously thought to be unrealistic; they build CubeSats for spaceflight, to which the author and team often refer to as "ridiculous goals."

Fig. 1. Student designed WCDT mission patch. Image courtesy Kevin Simmons

The lead author, however, also coined this term to incorporate the BLUE to stand for: Build, Launch, Utilize, and Educate using CubeSats, which is the primary goal of the company, BLUECUBE. Aerospace. When applying this theory to education, the results are increased student interest, increased participation, and exceptional work in STEM fields.

There is a concern in the United States that the STEM pipeline will not produce enough workers to fill the demand of a greying workforce [3]. STEM jobs represent an increasing percentage of the American workforce. The United States had 8.6 million STEM jobs in May 2015, representing 6.2% of the U.S. and a growth rate twice as fast as other jobs [4].

The US Bureau of Labor Statistics in 2014 noted while there were 8.3 million jobs in STEM, only 17% of high school seniors reported an interest in pursuing STEM careers [5]. There are many reasons for why this may be; however, Bedford suggests that students lack the motivation for STEM learning because of a student's belief that science cannot be learned—that it is instead an innate skill [6]. Canning, Muenks, Green & Murphy note underrepresented students continue to underperform their white peers, with this issue exacerbated by situational cues from educators who consciously or unconsciously reinforce racial stereotypes in STEM [7].

Children often base perceptions on what they are "good at" based on parents' perceptions of their own abilities in a subject. Since attitudes affect motivation, it is essential that educators find ways to help students believe they are future engineers, scientists, etc. The authors' approach to teaching young students is designed to not only foster a love of STEM early, but to also provide a basis for team building in relation to experiential learning and connecting education to industry in a novel way. In order to bring about a lifelong dream of flying spacecraft to fruition, the author inspired younger students to reach for the highest possibilities and provided opportunities for them to engage in problem-solving and project design through teamwork. The motivation behind successful teams has been studied from a few lenses, including coopetition, game theory, entrepreneurship, and growth mindset. When utilized together, the author has found students who work with teams produce a better product, produce more, and seem to thoroughly enjoy the experience.

1.1 Growth Mindset and BLUE-SKY Learning

Motivated children are excellent sponges and are easily excited by the prospect of doing "adult" work. Since they are young, they do not yet know that they "cannot" do something simply because they aren't old enough. They don't have the limiting beliefs that often set in as they mature, often due to peer and societal interactions. In short, children don't know why they should not be able to build a satellite, and when tasked with similar challenges, they enthusiastically undertake them. It is here where the real learning begins and sets a love of STEM in motion that may benefit them in the future.

The importance of establishing a growth mindset is extremely important in BLUE-SKY Learning philosophy. Carol Dweck notes "individuals who believe their talents can be developed (through hard work, good strategies, and input from others) have a growth mindset. They tend to achieve more than those with a more fixed mindset (those who believe their talents are innate gifts). This is because they worry less about looking smart and they put more energy into learning [8].

Having a growth mindset is especially important for teams to function well. When students recognize that the act of learning is more important than the knowing, they are motivated for the long term as opposed to the need for immediate gratification. In fact, Bedford notes that task value, self-efficacy, and self-regulation are motivating factors of having a growth mindset, all traits that are fostered with BLUE-SKY Learning. But it's not just the students who must believe in their own abilities. Students report feeling demotivated and had more negative experiences overall in classes taught by their fixed-mindset instructors [7]; therefore, it is important for teachers to embrace the BLUE-SKY Learning philosophy as a guide to positively affect their learning environments along with the diverse students within them.

1.2 Socio-Scientific Issue (SSI)

Students often see "task value" as lacking in science education. They do not see the application of their studies or see them as relevant to their lives. That's where Socio-Scientific Issue (SSI) comes in. SSI is a learning model that establishes communities where student identities can be expressed while using previously gained knowledge [9]. By building upon prior knowledge, deeper understanding of how science works in real life is gained. The design of these groups ideally places students in situations where they can experience decision-making, goal setting, problem, and resolution. Lundbland, Malmberg, Aresskoug, & Jonsson further describe SSIs as ways to make school science more important and usable outside the classroom [10]. To help address the lack of STEM career pursuit, establishing a belonging in science early on is important, and providing these opportunities is an objective of BLUE-SKY Learning, primarily in the formation of teams who both collaborate and compete with each other, creating coopetition.

1.3:Coopetition

Coopetition is generally defined as a theoretical lens to study the relationship between organizations involving competition in some segments and cooperation in others [11]. Most studies in this theory have been done in business organizations, breaking down into profit and not-for-profit. With regard to educational applications, coopetition is primarily associated with higher learning as colleges operating as businesses to recruit students; therefore, there is limited research on coopetition in the classroom as a means of education in small groups. Moczulska, Sieler, & Stankiewicz offer that while coopetition is primarily studied at the meso-level, it can be studied from the macro level when done within organizations as opposed to outside organizations competing with each other [12].

At the micro level, research in the future can focus on how people—in this case students—behave towards each other in order to achieve mutual goals. In order to be successful, coopetitive teams must have trust between collaborators and competitors alike. They must recognize the opportunity to learn from each other while they are still competing for that vison. Moreover, each individual must feel there are personal benefits from collaborating if the group is to operate successfully in the long term. At the same time, clear goals and agreements must be made between the members and the leaders. Proponents of coopetition suggest that there are several positive outcomes including innovation, sharing of knowledge and research, and the pooling of complimentary skills [11]; however, when used in a classroom, it is also the case that the organization itself (in the form of the teacher or the school) benefits as well. BLUE-SKY Learning keeps these findings in mind when creating teams.

1.4: Game Theory

One important component of coopetition is game theory, which seems obtuse at times in definition. Stanford defines it as "the study of the ways in which interacting choices of economic agents produce outcomes with respect to the preferences (or utilities) of those agents, where the outcomes in question might have been intended by none of the agents" [13]. Investopedia offers a somewhat clearer definition by suggesting game theory is a theoretical framework for conceiving social situations among competing players. In some respects, game theory is the science of strategy, or at least the optimal decision-making of independent and competing actors in a strategic setting" [14]. Proponents of this theory suggest that players (teammates or opponents) learn by taking action and reflecting on what they and others have done with regards to the "game" [10]. Turning work into a game where players are vying for advancement is not new. Gamification has been studied for its positive effects on learning. Using augmented reality/virtual reality (AR/VR) and simulations for modelling orbital maneuvers and planning space operations provide students with heightened visual cues and a realism that promotes deeper understanding. Examples include Analytical Graphics, Inc.'s Systems Tool Kit, or STK (https://www.agi.com/products/stk) and the Space Foundation's Mars Robotics laboratory (https://www.discoverspace.org/exhibit/mars-robotics-laboratory/). But students can still benefit when actual "games" or augmented realities are not used. This is where team formation and competing for shared goals comes into place. For the purposes of teambuilding and its application to BLUE-SKY Learning, it's important to consider multiple groups vying for multiple shared and desired outcomes.

2. Methods and BLUE-SKY Learning examples:

Competitive and cooperative teams are the best method to achieve results. It is an opportunity for students to both grow their strengths and to work on perceived weaknesses. By coopetitively working together, teams and the individuals that form them, learn from each other. As an individual, they may not have all the answers but together they can complete tasks that are worthy of BLUE-SKY Learning. Two such examples are space settlement teams and CubeSat development teams.

2.1 Space Settlement Teams:

One great example that embodies Design-Based Research is space settlement competitions, which require student teams to imagine a self-sustaining settlement in a predetermined location in space. Design studies and competitions "are test-beds of innovation with the intention to improve education by bringing in new technology with the purpose to mediate learning" [10] Since they are solving real-world problems, the opportunity for innovation is real. Students begin learning about these opportunities in a summer camp setting where several teams are formed. The teams are provided tasks and deliverables, which simulates coopetition at the micro level. Ultimately, teams decide on a representative plan, and they must present and defend their ideas to the other teams. These tasks include determining best locations, how to make the design cost-effective and viable, how to make the space habitable for humans (how will they breathe and eat), as well as societal concerns like employment, religion, psychological considerations and laws to govern future colonists. Then, ideas are narrowed and iterated until the entire group has come to a consensus. The author has a long history of space settlement design participation with several groups beginning in 2010. In that time, teams have collaborated internationally with students from around the world, and the teams have gone on to place in the International Space Development Conference (ISDC), even earning first in the 8th grade large team division amongst 2,600 teams and 14K+ student entries. High school teams participated in the Space Foundation's settlement contest, earning national champ status and securing a position in the Future Space Scholars Meet in Beijing, China in 2019.

The summer camp students of 2020 formed the newest team, known as the Wolfpack, consisting of students as young as ten years old. Within each group was a student leader, who would assign research and/or design tasks for each teammate to complete. Knowing they were up against other teams for the final settlement decisions made it both cooperative and competitive. Each student had a shared goal or purpose but there was excitement to "beat" the other teams in the process. Moreover, having student/peer leaders motivated others to know that they, too, could one day be a leader, which provided incentive to work hard and to be a supportive teammate. While the groups were competitive for overall selection, they demonstrated sportsmanship by interacting in a well-mannered fashion, even learning from each other in the process. Students describe their experience as being a "very fun, interesting and engaging way to learn."

While these design challenge problems seem too difficult for young students at first glance, they are exactly what BLUE-SKY Learning embraces: Choose a lofty and seemingly unachievable goal and break it into smaller pieces to achieve the larger picture. There is less concern over "failure" in these kinds of activities as students learn by mistakes or from not being selected, which leads to innovation and success for the larger group in the long run. Additionally, they reinforce a growth-mindset of grit and perseverance.

2.2: CubeSat Teams

Beginning with a planning meeting among a handful of students in August of 2015, the nascent Wolverine CubeSat Development Team at the Weiss School determined their simple mission statement: "To design, build, test, and fly a CubeSat into space within three years." Through a series of incremental deliverables (emulators, remote sensing tethered balloon payloads, high altitude balloons with GlobalStar radios and 900 MHZ video cameras, etc.) students gained confidence in both the processes and skills needed to see their first CubeSat come to life.

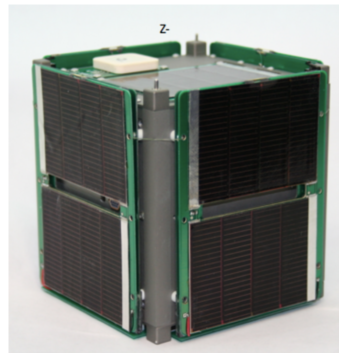

Fig. 2. First middle school CubeSat, the WeissSat-1. Image Courtesy Kevin Simmons

The 1U WeissSat-1 was launched as a member of Spaceflight Industries SSO-A mission via a Space X Falcon-9 from Vandenberg Air Force Base, California on December 3rd, 2018. Nominal deployment into a sun-synchronous orbit with an apogee of 575 km occurred at 4 hours and 39 minutes post launch and the first telemetry packets were received through a GlobalStar downlink shortly thereafter. As of July 17th, 2020, a total of 116757 bytes had been received in 12,975 data packets. The primary payload was a basic science experiment which considered the viability of extremophile bacteria in a low Earth orbit (LEO).

NASA categorizes all CSLI missions as either basic science, technology demonstrations, or education. While the WCDT students considered their primary payload as a basic science mission, NASA sees it as human capital development.

Fig. 3. Launch of the Falcon-9 carrying the SSO-A Mission Dec. 3rd, 2018 from VAFB. Image Courtesy SpaceX

The WCDT remain the only middle school (grades 6th-8th) program nationwide to have launched a CubeSat mission with NASA's CubeSat Launch Initiative (CSLI). Annually since 2017 this author and his students create numerous additional NASA proposals and submit them to the CSLI.

Students work in smaller groups both to create their own payload ideas and subsequent proposals. Once NASA down selected to a single proposal, all WCDT members are then considered part of the winning team. They are then broken into smaller groups to develop their own subsystem components, concepts of operations, or other mission parameters with the goal of eventually persuading the entire team that a particular group's contributions are the optimal choices; thus, there are numerous cycles of competition and collaboration within the team overall, with the understanding that in the end all are WCDT members.

The educational outcomes of forming small teams, creating their own missions, adhering to project management and CubeSat constraints, identifying NASA strategic goals, creating project timelines, and meeting milestone deadlines, all contribute to the real-world feelings of belonging to an authentic team doing "BLUE SKY" work. These aforementioned activities represent significant learning and growth opportunities for the students and clearly support the ideals of human capital development.

The WCDT was elected by NASA for a second CubeSat mission in 2019. The tenth CSLI round consisted of only 17 proposals, with WCDT's being the only K-12th grade entity. Others included MIT, Yale, Purdue University, and the University of Florida [15]. For the second WCDT mission, the CapSat-1 will be a technology demonstration as to the potential use of capacitors versus batteries in a novel CubeSat electrical power system, or EPS. The CubeSat will be assembled during the fall of 2020 and following acceptance testing is scheduled for integration. Launch, and operation in third quarter of 2021.

The WCDT leverages the excitement of young people towards aerospace and the accessibility of CubeSats to engage the next generation STEM workforce. While in the past only nations could build and deploy spacecraft, today CubeSats, in conjunction with NASA's CSLI, represent a pathway for middle and high schools to put their student-built satellites into space.

Building on the success of previous years, the Wolfpack was also given the opportunity to present future CubeSat proposals. Similar to the team design for space settlement, the Wolfpack divided into smaller groups to discuss potential payloads. Initially, the team task to research an idea that the creators and NASA would find interesting, so there is a higher chance the proposal will be accepted. If the payload idea is chosen, by the CubeSat Launch Initiative, then the team can start the process of building. This kind of motivation again represents the common purpose that is paramount to coopetition. Students collaborate to research and learn; they compete to have their ideas selected.

Many steps need to be taken before a proposal is even written let alone considered, which creates a long-term experiential learning experience. The new team of students first became interested in joining the overall team in 2019 by attending various aerospace events to assist their predecessors on The Wolverine CubeSat Development Team. Newbies, who were often in the fifth and sometimes fourth grades, had 'fun' learning the ropes through networking, and teaching those even younger than themselves, thus finding a passion for aerospace. Teams learn early that working together, they can solve and accomplish larger than life tasks, embracing BLUE-SKY Learning in their own lives.

The Wolfpack continued to expand their knowledge and by the Spring of 2020, began meeting bi-weekly to review NASA's *Cube-Sat 101* reference book as a guide [16]. Students learn about the technical components of CubeSats, regulations and processes required to be approved for integration and launch, etc. As with most things involving a large group of people, there were always different opinions—especially knowing that they were competing to have an idea selected. The lead author works closely with each team, questioning viability of payload ideas, which are then defended by the team. Team decisions are made democratically by debating which payload should be considered and then voting. Team voting and debating doesn't end with which payload makes the best sense but continues on in every decision that the team makes.

One early deliverable that requires a level of both collaborative competition, or coopetition was the team patch and mission patch design. Individual students were encouraged to submit initial ideas which were then voted on by the entire team. After reducing the field to two candidates, the students then collaborated with others to produce a final product for consideration. The team's final patch to represent the Wolfpack is in the shape of a symmetrical, pentagonal 'arrowhead', highlighting key symbols such as a wolf's head (to representing the Wolfpack), a CubeSat, the Earth with a focus on Florida (the team's home state), the moon (a future rover mission) and the stars (which symbolize the BLUE-SKY Learning philosophy).

One of the significant milestones achieved by individual team members is the receipt of their unit coin, which is the official symbol of membership in the WCDT. Students may earn their coins at various lengths of service through a combination of acquiring skills, making presentations, supporting WCDT events, mentoring others, and modelling high ideals of teamwork and shared purpose.

Fig. 4. Mission patch for the Wolfpack CubeSat Development Team. Image courtesy of Kevin Simmons

3. Theory

BLUE-SKY Learning is only possible when students embrace a growth mindset. Once this is in place, however, the sky is no longer the limit for what aerospace students can achieve. Creating an atmosphere of coopetition enables multiple teams of individuals to learn more, learn faster, and to take ownership in their own education.

Game theory was originally studied in the lens of mathematics, business, and even war, for its applications in understanding strategy. Over the years, however, the theory has expanded to be useful in studies where understanding how an individual will act when confronted with actions of others, especially if the actions are not in the individual's best interest. This is where the idea of competition comes into play, as opponents are often viewed as enemies to beat. But cooperative teams who are competing must also incorporate collaboration in order to achieve large goals, and this is where game theory is best applied in small teams. Mujis and Rumyantseva point to five key elements of game theory that apply in small teams: players, added value, rules, tactics, and scope [11]. The WCDT member students are the players in this scenario, and each of the unique student skill sets and individual enthusiasm are the added value brought to both the team and individual CubeSat proposal groups within the overall WCDT.

The lead author creates a strong sense of branding and culture to which the individual members strongly choose to identify, and along with *pro forma* expectations for professional behaviour, set the tactics for the members. The WCDT lead also teaches the principles of the lean canvas model for start-up companies in order to reinforce the principles of identifying needs and then meeting them through one's proposal and subsequent mission. Additional mapping of the rules, tactics, and scope are reflected in training of the students members with respect to three types of factors: 1. societal (private vs. public space efforts), 2. political (NASA's budget), and 3. market influences (increasing utility, customer demand, and growth of the small satellite market). All of the above affect the CSLI program and NASA parent organization.

With regards to teambuilding and BLUE-SKY Learning, game theory elements are of special note. Each of the teams within a larger team brings individual skills to the table that add into the larger scope or mission.

4. Results

From the first meeting in August 2015 until December 2018, the Wolverine CubeSat Development team not only accomplished their primary goal of developing and launching the first middle school CubeSat into space, they achieved numerous individual and team goals. Students gained confidence and regularly presented and exhibited their CubeSat work, advocated on behalf of aerospace policy and funding, and competed (often at a high school level or above). They annually update the City Council, visit the state legislature and Governor's office to advocate in person alongside companies for favourable aerospace policies and promote state-wide aerospace education reform. WCDT students have joined and routinely participate and present at numerous aerospace and engineering organization banquets, as well as forming one of only six high school chapters in the AIAA.

The students have been recognized as a national and international team champions in two different space settlement competitions, and have been selected to present or exhibit numerous times at SmallSat Conferences, International Space Development Conferences, Humans2Mars Summits, the Lunar and Planetary Science Conference, and the International Astronautical Conferences. The adult mentors of the WCDT have also been recognized with 6 national and regional level awards for teaching and mentoring excellence, been selected as Principal Investigators for three different NASA projects, and currently train educators to employ more authentic aerospace content.

Probably the most evident individual gains in student performance may be found in science and engineering fair results (Table 1). Several WCDT students conducted science fair experiments related to their current CubeSat missions. Over 90% of all Weiss students reflected in the below chart are WCDT members.

In addition to the previous accolades, WCDT student success may also be seen through their mentoring efforts. One of the clearly stated expectations for team membership is that the older (7th and 8th grade) students will mentor the younger students. Evidence of success in this area manifests as increased interest and quality of elementary student participation in aerospace summer camps, age-appropriate science and writing contests, and the school-wide elementary science fair.

Table 1. 6th-8th Grade Student Science Fair Results, The Weiss School, 2014-2020

	'14-5	Introduction of BLUE-SKY Learning	'15-6	'16-7	'17-8	'18-9	'19-20
Participated in school fair	0		60*	60	60	60	55
Invited to Regional Fair	1		5	21	30	30	30
Placed 1st-4th at Reg. Fair	1		5	17	27	23	23
Finished 1st at Regional Fair	0		2	5	10	4	3
Earned state Sci/Engr Fair Bids	0		2	5	9	3	3
Placed at State Fair	0		2	3	5	3	**
Placed 1st at State Fair	0		0	0	0	2	**
Grand Champions State Fair	0		0	0	0	2	**

*All Students in middle school **Cancelled due to COVID-19

5. Discussion

While there is limited study on the effects of coopetition and game theory in the area of early and secondary education, it is worthy to note how these components contribute to successful student teams who operate under a BLUE-SKY Learning philosophy. While working at this kind of level is not for every student, providing opportunities to be part of the "team" is often enticing to students who are at first reluctant or who don't see themselves as "scientists" or "engineers." SRI Education suggests a model for implementing a growth mindset within an organization prior to instilling it in the classroom. These suggestions include acknowledging that socio economic and learning environments can hinder growth mindset, but that students can adjust psychological attitudes when placed in learning environments that are supportive of development of grit [17]. They suggest using research based best practices, and to adopt programs that model growth mindset [18]. This is where BLUE-SKY Learning may come in. Since there is little research in these areas for younger students, the model becomes one that may be implemented for longer term study.

6. Conclusions

The BLUE-SKY Learning philosophy represents a potentially disruptive educational tool for the educator and has shown demonstrative results in terms of aerospace mission success in the real-world, but also in terms of individual and team performance gains and achievements. Gleaning elements from coopetition, and game theories, current entrepreneurial start-up processes, and a genuine interest in the theme, the lead author has created a vibrant and voluntary aerospace organization composed primarily of 10-14 year old students who perform at a much higher than expected level. Students are given freedom to contribute according to both their interests and abilities, with the ultimate aim of achieving extraordinary (e.g. 'ridiculous') results.

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