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A "fractal" expander-compressor-supplier formative research method on array processing

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Abstract

In the present research the typical triangle on formative research was extended to a double triangle for an overall career programme (here expander/ compressor) and funnel proposal was explored in a single course (as a "fractal" method). Array processing and ElectroEncephaloGram (EEG) techniques have been incorporated into a Digital Signal Processing (DSP) course and research projects. The present research question was: is it possible to insert array sensing on formative research in an undergraduate course of DSP? From over eight years, two semesters with different homework loads (homogeneous triangle vs expander-compressor-supplier distributions) were analysed in detail within the DSP evaluations and students chose between experimental applied analysis and a formative research project. Results showed that cognitive load was influenced positively in the expander-compressor-supplier distribution, showing that an increase of the efficiency undertook more undergraduate research on array processing and the decrease of the number of formative applied projects. Over a longer term (48 months) students undertook more undergraduate research works on array processing and DSP techniques.

Keywords Array Processing · Digital Signal Processing (DSP) · Cognitive load · Undergraduate Research Methods · Student Outcomes/Success · Homework load distribution · Digital Signal Processing (DSP) · Education management · ElectroEncephaloGraphy (EEG) · Formative Research · Independent Component Analysis (ICA) · Information and Communication Technologies (ICT) · Science, Technology and Innovation (STI)

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1 Introduction

Today, improvements in educational coursework related to direct course applications and formative research are needed. Learning activities that convey information for learning and the "cone of experience" has been debated for over 50 years (Dale, 1970). The time spent by students on different learning activities was defined and limited, bearing in mind the sequence in overall activities an allocation can lead to 157 learning designs using the taxonomy of seven different learning activities (Toetenel & Rienties, 2016). Therefore, time devoted to a single course can only be allocated once, but in different ways for the same objective. The present tested ways (expander/compressor) to enhance formative research in courses such as Digital Signal Processing (DSP). This is especially true in regard to issues of array processing and signal processing related to ElectroEncephaloGram (EEG), the external sensing of electrical signals on the scalp. Because the present research investigates multiple areas, the introduction has been divided into three parts: array processing and EEG, formative research, and cognitive load. Other pre-requisite signal processing works were used as a basis for the present proposal (see Supplementary Material 1).

EEG recordings began more than 80 years ago. The seminal article by Loomis in 1935 showed the capture of eight electrodes in periods of one minute (Loomis et al., 1935). Reports of blink processing in EEG first took place around 45 years ago when term array processing began to use digital electronics to perform the computation. For example, computation is associated with the reception of signals of a set of electrodes, antennas or directional matrix including mathematical and intuitive descriptions of the relationships needed (Dudgeon, 1977). A further example used since 1996 (see Supplementary Material 1) is Independent Component Analysis (ICA), achieved by maximising the entropy of a non-linear transformation vector. In this way, the weight matrix (W) was initially adjusted with the ascending stochastic gradient (1) to calculate the independent components (x) of the data received (y) by EEG where also $\Delta w\ \alpha\ y$ (Makeig et al., 1996).

$$\Delta W \alpha \left[W^{\mathrm{T}}\right]^{-1} + yx^{\mathrm{T}} \tag{1}$$

The second part of the introduction deals with formative research related to undergraduate electrical programmes. Courses related to electronic engineering included lectures that allow institutions to prepare human resources in signal processing cognitive neuroscience (Mugruza Vassallo & Mugruza Vassallo, 2018). Moreover, it was suggested that the individual courses be disseminated to help the labour insertion of non-ordinary cognitive routines for 2014 mentioned by Zappa (Zappa, 2012). An analysis based on coursework and student access to peer review databases reported that top Peruvian universities have lower IEEE access than other universities with coursework related to cognitive neuroscience (Mugruza Vassallo & Mugruza Vassallo, 2018). That study showed how students may understand recent developments using the programme to improve articulation between courses. In this present research, results for completed undergraduate DSP courses were shown and analysed. Different implementations of formative research in the two programmes can be seen in Supplementary Material 2.

The third part of the introduction looks at how cognitive load was used in a number of studies, some of them randomised controlled trials and have shown little effect in regards encouraging or hindering learning (see a review by Ginns, 2005). Moreover, flipped classroom approaches were proposed for additional opportunities to manage cognitive load in improving learning. Abeysekera and Dawson theorised that the flipped classroom approach required that lecturers make choices when designing learning activities (Abeysekera & Dawson, 2015). Moreover, Chaeruman et al. (2020) developed an instructional system design tested with good feedback from supervisors and expert reviewers but without a clear cognitive load balance to address students in formative research. Therefore cognitive load needs to be tested for improved learning outcomes, in this present research to test in array processing to formative research.

Having reviewed DSP, formative research and cognitive load, the present question arises: how do the academic programmes and the workload of the course affect student performance and learning? More specifically in a complex theme such as array processing: is it possible to use the expander-compressor with a funnel for formative research? In the literature reviewed, the focus was on antenna arrays (not on EEG) according to PubMed, ScienceDirect and IEEE Xplore searches conducted until March 2018. Therefore, this study's aims were twofold: a) bring the main conclusions of discussion and preliminary processing of recent research in array sensing and EEG techniques in engineering to undergraduate programmes, and b) analyse the cognitive load of DSP undergraduate courses.

2 Methods

The current research presented here extended the application of a double triangle (here expander/compressor) and funnel proposal for overall career programmes giving a "fractal" method in formative research for a single course. Figure 1 considers

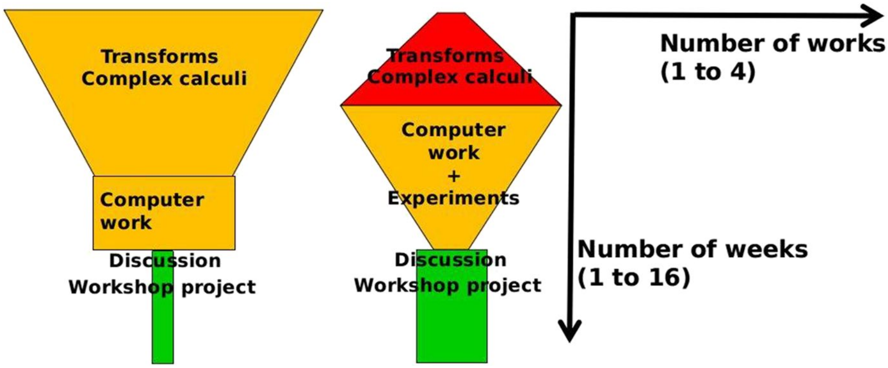

Fig. 1 The different methods explored 2.2, 2.3 and 2.4 in a triangle (2014–2 to 2017–1, left) and expander-compressor (2017–2 to 2021–2, right) homework load distributions. The vertical axis is the number of weeks prioritised in terms of evaluation

the different methods explored in sections II.2, II.3 and II.4 and considers the best learning outcome of polynomial operations and the calculi associated in DSP and observed in 2014–2 to 2017–1 and 2017–2 to 2021–2. The expander part of the course was in the first few weeks and had one homework per week with the amount of homework increasing to week 4 or 5. Then in the compressor part, computer work and experiments were required within small groups, to finally produce a workshop project and a formative research discussion as the result of the present undergraduate research methods tested.

The course evaluation was calculated by using (3). This evaluation facilitated methods 2 and 3 of this work.

$$\text{Final degree} = 0.3\text{LW} + 0.1\text{AW} + 0.3\text{ME} + 0.30\text{EE} \tag{3}$$

where:

LW are the qualified workshops here as Laboratory Workshops,
AW are the Academic Works,
ME is the Mid-Term Exam,
EE is the End-Term Exam.

2.1 Participants

The DSP course analysed included from 2014–1 to 2021–2 semesters. The extensive student's outcome analysis with 48 months follow-up was done in the 26 students of 2017–1 and 28 students of 2017–2.

2.2 DSP in electrical engineering analysis

The DSP course is taught regularly in departments related to Computer Science and Electrical Engineering globally. For example, the *Pontificia Universidad Católica del Perú* (PUCP), *Universidad Nacional de Ingeniería* (UNI, Universidad Nacional de Ingeniería. 2014; Universidad Nacional de Ingeniería. 2016) in Peru, and the *Universidade São Paulo* (JupiterWeb, 2015a, b, c) in Brazil, the University of Edinburgh (Undergraduate Course: Speech Processing, 2018) in United Kingdom and the University of Harvard, Massachusetts Institute of Technology (MIT Webpage, 2015) and Washington University in St. Louis in USA. Brazilean, British and American universities appears on the top on ranking universities (QS TopUniversities, 2015).

In this section, students' state and their calculation methods for DSP were explored. It was not directly computed in (3).

2.3 Array processing in coursework at DSP (LW)

In this section, based on (3), students were mandatorily evaluated in array sensing from lectures and laboratory workshops (LW) and optionally in array sensing at paper discussion (ME, EE), as described in the following subsections.

2.3.1 Array sensing teaching and laboratory (LW)

In the DSP course, array processing was introduced as a dynamical system consisting of “m” sensors thathave arbitrary locations and arbitrary directions (directional characteristics) in an array. Algorithms were used and modified in Octave GNU, Matlab and Python (Anaconda and GoogleColab) as can be seen in Supplementary Material 3.

2.3.2 Array sensing at paper discussion (ME, EE)

In each semester, analysis and discussion at mid-term (ME) and final (EE) exams were done in groups of two students. Presentations consisted not only of understanding two articles but also in the discussion of two additional articles for each of them. The evaluation was comprised of:

15% for the method used in the article, emphasising the DSP either in its mathematical model, use or construction,
10% for the results shown,
30% for the discussion of the work presented based on at least two additional articles or papers in the literature, and
15% for the presentation summary given for each article (objective up to 80 words, method up to 300 words, results up to 300 words) and a discussion of up to 800 words (which is the discussion based on at least two additional papers) in WORD document format. The students’ report was also reviewed on the day of the presentation and the corrected version was sent back no more than five days later, assuring additional learning and writing of students, i.e. adult learners of young adult learners.

And finally 30% for showing examples in MatLab, Octave or Python and clearly explaining the code.

Additionally, in 2017–2 to 2021–2, the grade was averaged with the DSP module Project Formulation and Management. The project was suggested to be in the area of the paper chosen for discussion.

2.4 EEGLAB to introduce array processing in DSP

Based on (3), students were evaluated in their mandatory Academic Work (TA) and their use of EEGLAB for array processing.

To include array-processing in the DSP course, some of the routines used by students for their Academic Work were on EEGLAB.

The EEG recording and processing example was introduced in 2017–1 and collected here up to 2021–2. A public EEG database released by Schalk et al. (2004) was used. As a part of their work in DSP course, students needed to use their basic array processing knowledge to analyse one participant of the public database by Schalk et al. (2004). For example, in the homework at LW number 2 in DSP, the students were given a week to:

A) Calculate, show and analyse the spectra of the 14 signals in the public database (70%)
B) Analyse signals from frequency bands less than 4 Hz, 4 to 7 Hz, 8 to 11 Hz, 16 to 31 Hz and greater than 32 Hz (30%)

Other questions were asked in LW number 4. The student's response to changes in topic and the form of DSP course evaluation in undergraduate students in two consecutive groups at UNTELS (2017–1 and 2017–2) was analysed up to 48 months after the course. In such a sampling, student errors were located qualitatively.

2.5 EEG formative research in electrical engineering undergraduate students

A three-week long DSP workshop was proposed for students who had chosen paper discussion (2.b) in EEG. In this study, the method is different from that indicated in Mugruza-Vassallo (2017), when a group of engineering students was complemented in the study of cognitive neuroscience. This DSP workshop sought to help students propose their undergraduate dissertation profiles.

Therefore, in 2017–1 eleven students were invited to take the workshop, of which seven students participated.

And, in 2017–2 four of the 28 participated in the workshop, proposing original final projects.

A 48-month undergraduate work was followed in 2020 and 2021 by meetings using Google Meet; including pandemic time and following some strategies as Andrade-Arenas et al. (2022) have worked with Zoom.

3 Results

3.1 Electrical engineering in DSP analysis

To the knowledge of the present author, PUCP, UNI and now UNTELS were using the revision and discussion of research articles in their undergraduate classroom. In the DSP course at UNTELS, resources of section II.2a were reviewed and explained theoretical bases in array processing such as the independent components analysis on Fast-ICA version (Hyvarinen, 1999; Gävert et al., 2005) and suggested to review Extended-ICA in EEGLAB as well.

In the former evaluations, some students had serious problems using the calculi associated with different signals. In the experience of this author and several colleagues in courses related to signal processing, Z-transform which carries the digital approach for signal and processing use to evidence the conceptual problem of handling of algebraic expressions (see Supplementary Material 4 and Fig. S1).

An explanation of the source of these errors (e.g. Fig. S1) was conducted by comparing similar DSP courses taught at Scottish Universities (see Table 1). Sequence variability was observed not only in the courses but also in the number of courses. The numbers ranged from a few (e.g. UCH) to several courses (e.g. UTP). At first

Table 1 Courses related to DSP in universities: Semester of each course & total number of courses

	Series&Transforms	Numerical methods	Signal & Systems	Comm 1	DSP	DSP 2	Voice processing	Medical instrumentation	Medical Imaging	Image processing	Digital Imaging Processing &Computer Vision	Neural Networks & Fuzzy Logic	SP systems	Reference	Number
Scottish Universities															
University of Edinburgh			5												4
University of Strathclyde	4		5	6	7	8					8		8		7
Heriot-Watt University	3		4		7	8				8					5
Aberdeen University	4		5		6										3
Paisley University	4		5	6	7	8				8					6
University of Edinburgh			4	5											
Peruvian Private Universities															
Pontificia Univ. Católica Del Perú-PUCP	5			6	9				9						4
Univ. de San Martín de Porres-USMP					8		9	9							3
Univ. Ricardo Palma-URP		6			9										2

Table 1 (continued)

	Series&Transforms	Numerical methods	Signal & Systems	Comm 1	DSP	DSP 2	Voice processing	Medical instrumentation	Medical Imaging	Image processing	Digital Imaging Processing &Computer Vision	Neural Networks & Fuzzy Logic	SP systems	Reference	Number
Univ. Peruana de Ciencias Aplicadas-UPC	5		6		7					8					4
Univ. Tecnológica del Perú-UTP	6				11						12	12			4
Universidad de Ingeniería y Tecnología—UTEC			5		8										2
Universidad Telesup			5		8	9									3
Universidad Católica de San Pablo—UCSP			5		6										2
Peruvian Public Universities															
Univ. Nacional Mayor de San Marcos-UNMSM		5			8		10			10					4

Table 1 (continued)

	Series&Transforms	Numerical methods	Signal & Systems	Comm 1	DSP	DSP 2	Voice processing	Medical instrumentation	Medical Imaging	Image processing	Digital Imaging Processing &Computer Vision	Neural Networks & Fuzzy Logic	SP systems	Reference	Number
Univ. Nacional de Ingeniería- UNI	5	5			8	9									4
Univ. Nacional Federico Villarreal- UNFV					7										1
Univ. Nacional Tecnológica de Lima Sur- UNTELS		5			9										2

glance, the results showed no consistent pattern among universities, having not top Peruvian universities with a higher number of courses.

Systems Engineering, Computer Science and other similar coursework career names have not been included, since they do not present similar courses in the different universities, e.g. PUCP, University of Lima and others. Moreover, at the University of Edinburgh, DSP was found in just one course, the syllabus of Speech Processing modules (LASC10061, 2018). In Brazil, *Universidade Sao Paulo* has only two courses in Computer Science (JupiterWeb, 2015a, b, c).

Comparing the results of the number of courses with previous research (Mugruza Vassallo & Mugruza Vassallo, 2018) the total number of courses related to DSP were four for private universities with the greatest number of students PUCP ($n=691$) and UTP ($n=593$) (Mugruza-Vassallo, 2016). Moreover, the present results for public universities for a good number of electronic engineering students UNMSM ($n=528$) and UNI ($n=425$) (Mugruza-Vassallo, 2016) were the greatest with four courses.

Table 2 shows the development of the solving filtering calculi. On average, students in 2017–1 got around 26.9% in the first homework (e.g. Fig. S2 in Supplementary Material 5) on OPerational AMPlifiers (OPAMPs) with an increase in the following homework up to 69.2%. Conversely, in 2017–2 the scores remained similar with only a slight percentage reduction of the total number of students initially enrolled, successful scores were from 75% to 64.3%, with an average of 69.2%, similar to that of 2017–1.

3.2 Array processing in undergraduates student discussion of peer review publications in expander-compressor distribution

The time used to prepare for discussions and presentations per group ranged from two to six weeks.

Results are shown in Table 3. In 2017–1 there was shown to be an increase in the number ($n=8$ to $n=18$) and in the percentage of the work performed (32.5% to 55%). In contrast, 2017–2 saw a decrease in the number ($n=19$ to $n=12$), and a slight decrease in the percentage of work performed (45% to 41.5%) was observed. A t-test was performed between different assignments and showed a significant difference ($p=0.00439$ and $p=0.00018$ in Table 3).

3.3 EEGLAB introduced array processing in DSP was better in expander-compressor distribution

Table 4 shows the development of the students' work in 2017–1 and 2017–2. The number of students who performed an EEG analysis decreased from n = 13 (2017–1) to n = 6 in the triangle distribution (2017–2), with the average score being (58.85% to 80%). In the expander-compressor distribution (2017–2), specific problems not solved in the literature were also proposed. Some of them emerged from the fields studied alongside EEGLAB and array sensing, showing the success of this step of formative research (see example using 32 independent components in

Table 2 Output of incoming in polynomial filtering operation and opamp processing in the undergraduate ICT programme tested at UNTELS on transition

Student ID	2017–1			2017–2	
	PP(1) opamp 1	PP(2) opamp 2	PP(3) opamp 3	PP(1) opamp 1	PP(2) opamp 2
1				ok	ok
2	ok	ok	ok	ok	
3					
4	ok	ok	ok	ok	ok
5	ok	ok	ok		
6	no found	ok	ok		
7				ok	ok
8	ok	ok	ok	ok	ok
9	ok	ok	ok	ok	ok
10	no found	ok	ok	ok	ok
11	no found	ok	ok	ok	ok
12		ok	ok		
13	ok	no found			
14		ok	ok	ok	ok
15	ok	no found		ok	ok
16		ok	ok	ok	ok
17	unexplained	ok	ok	ok	ok
18				ok	
19	unexplained	ok	ok	ok	ok
20		ok	ok	ok	ok
21	unexplained	no found			
22	unexplained	ok	ok	ok	ok
23		little	little		
24		ok	ok	ok	
25		ok	ok	ok	ok
26	unexplained	ok	ok	ok	ok
27				ok	ok
28				ok	ok
Success	7	18	18	21	18
%Success	26,9%	69.2%	69.2%	75%	64.3%

Fig. 2). EEGLAB in Octave (and Matlab) and now MNE in Python used to be for research. Here, these good platforms were good to teach ICA.

Students had four weeks to choose between participation and data analysis from an augmented reality experiment or an in-depth EEG data exploration by Schalk et al. (2004). This resulted in six students carrying out this EEG processing activity in 2017–2. Figure 3 shows an example of the quality and implementation success. As shown in Fig. 3, some student reports were completely handwritten which

Table 3 Array processing discussion in the undergraduate ICT programme at 2017–1 ($n=26$) & 2017–2 ($n=28$)

Student ID	2017–1 (triangle)		2017–2 (expander-compressor)	
	First case (ME)	Second case (EE)	First case (ME)	Second case (EE)
1	0	0	7.5	nsp
2	9.5		8	nsp
3			NSP	nsp
4		10.5	11.5	16
5		10	NSP	nsp
6	2		0	0
7			9	7
8		18	14	13.5
9		8.5	3	2
10		8	6.5	0
11		14	8.5	nsp
12	5	10.5	NSP	nsp
13		10.5	NSP	nsp
14		8.5	11	4.5
15	3.5		14	16.5
16		10	10.5	4.5
17		8	7	3.5
18			2.5	nsp
19	7.5	12.5	10.5	8.5
20		10.5	7	0
21			0	nsp
22	9	9.5	13.5	9.5
23	8	14	NSP	nsp
24		8.5	4	nsp
25		8.5	11.5	16
26	7.5	18	7.5	1.5
	x	x	8.5	4
	x	x	13.5	9.5
Mean	6.5	11	9	8.3
T-test		0.00439		0.00018

NSP The student did not present array processing work.

emphasised not only an attempt to understand the techniques but also what conclusion can be inferred from the results.

An explanation of the differences relied on the fact that in semester 2017–2 the students were able to choose whether to participate in an experiment about augmented reality analysed in section III.5.

Table 4 Array processing use in the undergraduate ICT programmes at 2017–1 (n = 26) & 2017–2 (n = 28)

Student ID	2017–1	2017–2
1		70
2		
3		
4	65	
5	60	
6		
7		100
8	65	100
9	75	
10		50
11	65	50
12	65	
13	60	
14		
15		100
16	75	
17	30	
18		
19		
20	60	
21	25	
22		
23		
24		
25	65	
26	55	
	x	100
	x	70
Mean	58.84615385	80
		3.48888E-05
number	13	6

Clear spaces: Students that did not want to choose this optional homework student

3.4 EEG—Array processing in formative research enhanced by expander-compressor distribution

In 2017–1, seven students were interested in the topics of computational and cognitive neuroscience (Table 5). Therefore, a workshop on scientific initiation was held for problem formulation forthree weeks between August and September. In this workshop, four undergraduate research proposals were made to the UNTELS undergraduate theses grant application board.

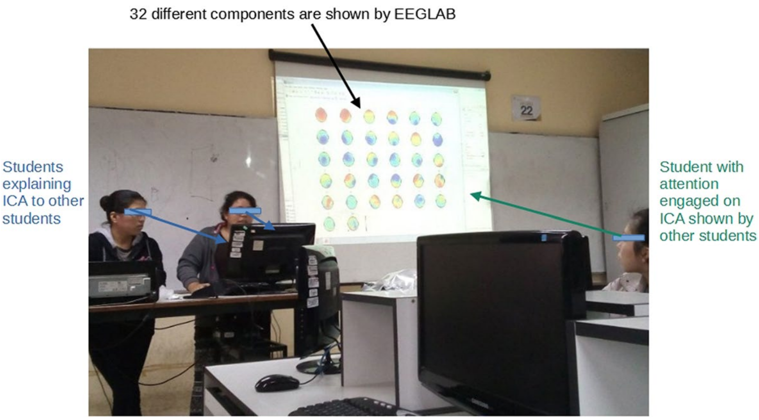

Fig. 2 A discussion reported by students of EEGLAB analysis in the DSP course at 2017–1 at UNTELS. See the Independent Components in their presentation

Main results were found after 48 months. Two dissertations were later submitted and approved in 2018 (Andrade Huaman, 2018; Huamani Atao, 2018). Due to Covid-19, other two dissertations were delayed (Quito Huaycañe, 2020; Suarez, 2021) which investigated a device (hardware components and software) for managing a set of gestures and consequently reacting with high precision to the gestures of patients who had undergone tracheostomies and were experiencing subsequent problems with speech phonation. All this was achieved with an Intelligent Finger Device to Improve Communication in Post-ICU tracheostomies Patients at the *Maria Auxiliadora* Hospital in *San Juan de Miraflores*. Suárez's development is currently in writing-up for a patent application in the Peruvian Patent Office.

3.5 Mixing array processing and EEG results

Considering the four-fold different results in the previous sections, here two interpretations are done:

3.5.1 Time needed for learning consolidation

A behavior similar to classical conditioning was observed in 2017–1 when the new papers discussion activity was added. An increase in the result of the aims of digital filtering and digital processing were observed through the polynomial handling of filters and sinusoidal signal (section III.1, Table 2).

Moreover, as shown in Fig. 4, there was an additional increase over the 2017–1 period in the research problems. However, during the 2017–2 semester there was a reduction in student's participation (see the dashed line in Fig. 4). Conversely, eas shown in Fig. 4, there was an increase in the percentage of the description (efficiency in the continuous line in Fig. 4) of the formative research development

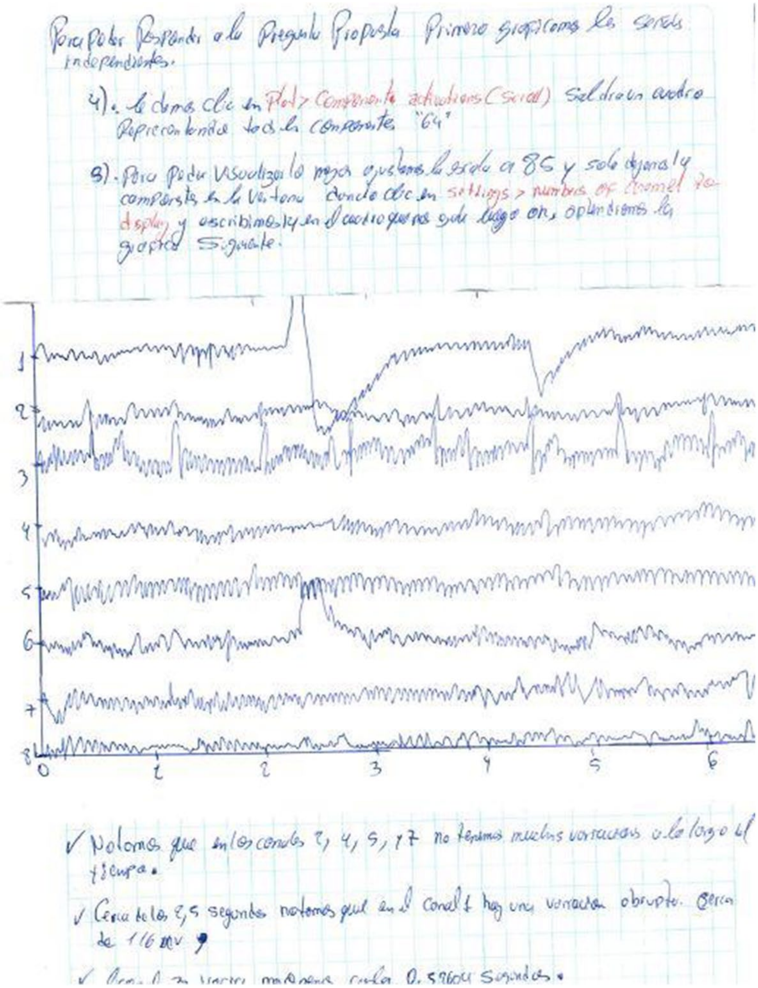

Fig. 3 A handwork reported by one of the students using ICA analysis in EEGLAB on 2017–2 at UNTELS

Table 5 Formative research proposals base on array processing in the undergraduate ICT programmes at 2017–1 (n = 26) & 2017–2 (n = 28)

Student ID	2017–1	2017–2
Time	3 weeks	3 weeks
Sessions	8	12
Invited	26	28
Participated	7	8
Finished	4	4
number	13	6

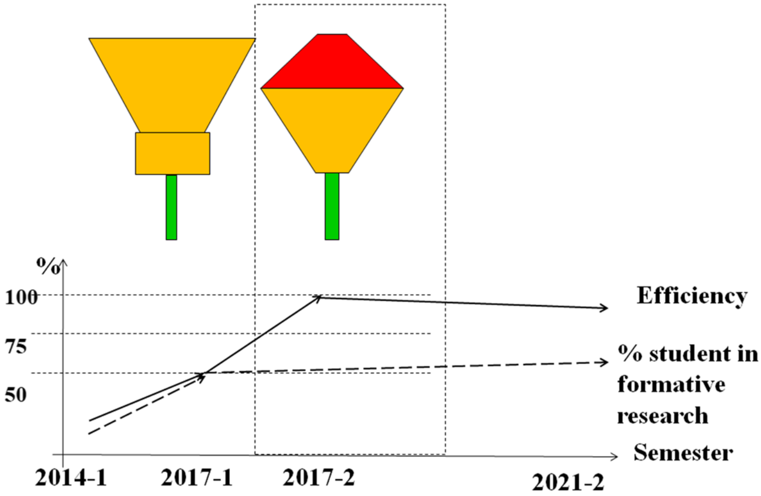

Fig. 4 Combined results of efficiency and percentage of students who are involved in formative research (section III.1, Table 2 and section III.3, Table 4)

proposed by students (section III.3, Table 4). Student Outcomes/Success was good at expanser-compressor-funnel distribution. Therefore the "fractal" worked well from DSP course to overall coursework.

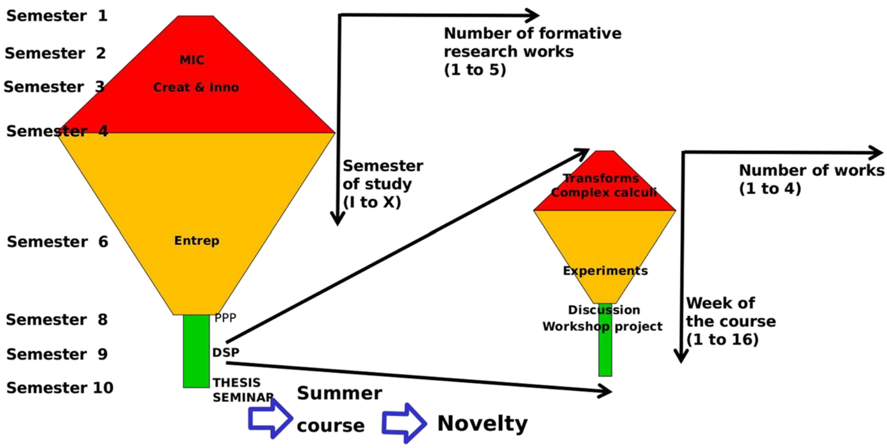

Fig. 5 Theoretical design of project management for each undergraduate thesis work (on the left, adapted from Mugruza-Vassallo, 2016), where DSP (on the right) would be almost finishing the degree, resembling a fractal

3.5.2 Total number of courses and cognitive load for learning

Using the Electronic Engineering perspective described in (section III.1, Table 1), the number of courses was close to four in the UTP, PUCP and UNI, while in the university where this testing took place UNTELS, was lower with only two courses. In addition, an increase in performance while at the same time, a decrease in the number of students was observed (section III.4, Table 4).

Figure 5 shows the different methods explored in II.2, II.3 and II.4 and considers the reasons for the effective learning of polynomial operations and the calculi associated with DSP that were observed in 2017–1 and 2017–2, being slightly more satisfactory in 2017–1. Overall, expanser-compressor distribution (2017–2) was better considering the level and number of papers analysed, the formative research and new ideas. Figure 5 clearly shows (on the left) that Formative research coursework has at least double-level generations with a long main sequence and many well-aligned side homework (as branches), resembling a fractal tree.

If the previous analyses are combined, it can be seen that the students who did not receive a sequence of courses have shown increased efficiency inverse to formative research success. The results of the two behaviors observed can be explained by: students who observed the changes and performed outstandingly when the course followed an expander-compressor and funnel, and students who did not necessarily follow the course and 2017–2 revealed that they might not have been aware of its utility. A further view was to divide into two courses: DSP and Voice and Imaging Signal Processing in 2019–2. This was approved in 2021. Moreover, adapted electronic programming courses were added in the third and fourth semesters.

4 Discussion

Expander-compressor and funnel have shown to be a reasonable implementation in a single course, building on the ideas of Peñaloza-Ramella (2005) and Mugruza-Vassallo (2016). Here, the lack of adequate course prerequisite has shown an inverse relationship between efficiency in solving exercises and conceptual mistakes (see Figs. S1 and S3). Moreover, significant improvements were introduced to students at UNTELS in papers read and discussed with regard to array processing and EEG and in the resolution of linear and delayed systems based on Z and Fourier transformations. Also, non-top universities with the highest number of students seem to have an articulation between several courses and obligatory areas to attract more or better students to their institutions.

One point of view was that most DSP courses in Peruvian universities were using only the resources available from personal computers without exploiting connectivity or external sensing, possibly due to a lack of equipment or knowledge. Moreover, this work has not found its way into other Peruvian universities using EEG for signal processing courses and the present experience in undergraduate DSP courses at UNTELS may be extended to other departments related to electrical engineering.

4.1 Cognitive load and learning

DSP and similar courses use visual imitations of programming languages and time have been implemented similarly (Baldwin, 1996) as well as consolidation (Sabitzer and Pasterk, 2014) that canbe explained by reinforce learning (Alexandre, 2021). However, this present work has found that learning within the first few months (section III.3) is given by imitation but in direct function of the efficiency and inverse of the number of participants. This participation may be related to the previous state (in knowledge and skills) where students acknowledge the lecturer, taking advantage of their classes (INEI, 2014).

This work added results and quantitative analysis to educational studies, complementing the management of indicators used and proposed for several courses (Mugruza-Vassallo, 2017). Specific changes to a course for senior students confirmed the hypothesis-driven mode of higher cognitive load metered in the same course for better learning through the dosing of evaluations in possible homework.

Bearing in mind the vision of education as cognitive science (Mugruza-Vassallo, 2017) and how to improve on skills and knowledge (Ruane, 2014), here it is considered that because of the cognitive load effects on learning, the results are similar to the attention part of Lavie (2005). With the repetitive evaluation of Fourier transforms and cascade filter calculi establishing circuits of memory and abstraction for learning.

Finally, as shown in Fig. 2 of the present work, it can be seen how the student (on the right) sees and has her attention on the presentation of other students. This seeing and attention are similar to a computer game as being stand up (Kadosh et al., 2013) as well as the behavioral intention that can be a mediating variable for use behavior (Zacharis & Nikolopoulou, 2022). Therefore further work would be to monitor this response and the influence or modulate of the dorsolateral prefrontal cortex.

4.2 Formative research suggested a nest expander-compressor and funnel

The current results are consistent with the problems and views of the programme where lecturers coach students through “Challenge-Based bachelor end projects” (Pepin & Kock, 2021) and undergraduate research program (Richter & Nehorai, 2016), which then complement the analyses made of the different approaches and number of works given during the semester. The lack of a sequence of courses in formative research was proposed as a cause of poor results in the number of undergraduate dissertations (Mugruza-Vassallo, 2017). The present results showed different approaches considered for each university, specifically at differences in the number and sequence of courses shown in Table 1.

The result of the concept error indicated in algebraic calculi (e.g. Fig. S1) reaffirmed the insufficient mathematical preparation indicated by (Mugruza-Vassallo, 2017) in Peruvian high schools. Following this, the first semesters in the curricular programme proposed by (Mugruza-Vassallo, 2017) encourage students to increase their skills and diversify their knowledge (see a red triangle in Fig. 5). Following these changes, in accordance with the triangle of Peñaloza-Ramella (2005) the number of works analysed decreased (see a yellow triangle in Fig. 5). Finally, the formative research project becomes more effective when finished such as a funnel with an undergraduate dissertation (see green line in Fig. 5). Figure 5 shows the few existing courses that optimise formative research at UNTELS which were listed in Table S1 (in Supplementary Material 2).

Following the education "small-scale" term of van Akker (2003), in the present research was implemented the adaptation of the double-triangle model first increased (expander) knowledge through systematic homework. Then materialising in (compressor) discussion of literature reports and following the funnel seeking the student to work on a project based on the course. Although the expander-compressor succeeds, in order to get a greater percentage of students, it would help to have formative research carried out in a similar way to the programme Fig. 5 (left part) following a "fractal" formative research for array sensing. As proposed by Mugruza-Vassallo (2016), the present study supported the idea that formative research should be carried out over a longer period of time (number of semesters) and the expander-compressor-funnel triangle could be applied in some courses to increase the success of formative research.

As shown in Table 1 (section III.1), courses in Scotland are connected, but it was not found in published analyses or trends in undergraduate research projects. However, the trend might be reversed according to a report from St Louis Washington University (Baldwin, 1996), which reported implementation results in 10 years' time. The present work has shown this time can be shortened using the double triangle and funnel inside a DSP course.

The present research has shown that the homework (PP, EF, FF) with different assignments for each student helped to reduce plagiarism while increasing the number of works done as was previously reported by Mugruza-Vassallo (2016). Moreover, over the long/term period 48-months following the course, COVID-19 pandemic time appeared and although students and advisors were affected in supervision monitoring (e.g. UCH in Andrade-Arenas et al., 2022) more students finished their undergraduate work dissertations on array processing.

4.3 Specific applications

Mugruza-Vassallo (2017) indicated that Chinchilejo was a local legend that ICT was helping to be preserved (Mugruza-Vassallo, 2016), thanks to the initiative of the students and guided by local employment proposals. In this work conducted at UNTELS in Villa El Salvador: on 2017–1 three projects were proposed in order to study and improve childcare conditions (see section III.4). Moreover, in 2017–2 proposals linked to ICT allowed the university to lead in local improvement. In other countries, single applications of array processing development as a borderland activity gave outcomes as an international disaster monitoring satellite constellation spin/out.

Although data for analyses were worked with projects at ULIMA on augmented reality, Mugruza-Vassallo & Mugruza-Vassallo (2018) suggested topics to associate naturalistic and sociocritical aspects with different Peruvian regions. This work, by improving the skills of students through laboratories in undergraduate courses including EEG, sought to enhance the areas involved in Cognitive Systems, through suitable equipment in EEG along with sound and camera accessories. This made it possible to study the different ways to visualise and listen to stimuli, including comparisons between the 2D, 3D and augmented reality which are current issues that require signal processing.

4.4 Technique in array-processing and EEG

Here, an almost simultaneous development between filtering and array processing theory and further applications in EEG and augmented reality were done. Part of the DSP course was related to the parallel papers with DSP code analysis as a part of their evaluation, giving a rise to higher course grades (Pluzhnikova, 2014).

One point of improvement was the introduction of topics in signal processing systems (see EEGLAB management in Fig. 2). This issue was partially seen in the DSP course, but not optimally, due to the unexpected wrong algebraic operations found in the course. The unexpected algebraic operations were reported to be emphasized in the previous courses and the first university courses. Finally, future versions of the course should emphasize an additional initial practice of basic signaling to align students.

Therefore, this work has confirmed that the local initiative is more reliable to find, even in unfavourable conditions as Mugruza-Vassallo (2017) suggested.

From the above, the specific objective achieved was in processing signals from brain electrical activity with EEG of 16 channels in the undergraduate course during the two reported consecutive semesters followed up after 48 months.

5 Conclusion

In conclusion, the different distribution of homework of the course affected the performance of students during the 16 week study period investigated here. Therefore, a different distribution (seen as a different cognitive load) resulted in a different learning approach for the students.

A funnel followed by an expander-compressor, the DSP course network resembling a fractal tree design on the coursework was tested by formative research results over homework and continuous follow-up.

For a complex subject, such as array processing, using an expander-compressor to plan and implement the workload with a funnel was beneficial for formative research in the 16 week study as well as in the 48 month follow-up when several students wrote undergraduate dissertations.

6 Limitations and future works

The following limitations and future works arose after the intervention through two different homework distributions: The course was given in Spanish while programming resources and papers to review were in English. Although English understanding is required in the fourth semester, some students in the ninth semester reported difficulties reading papers. Students have used Google Translate and a few misunderstandings in technical terms happened.

Rhythmic reading can be different in person compared to remote online classes (Beck & Konieczny, 2023). This would result in an extension of the present study. Even more, when magnetic stimulation (Argyropoulos, 2020) is used. Although it is not an English class, bearing in mind that array sensing implies more cognitive resources. What will happen if learning in this kind of fractal in formative research, will it change the learning distribution inside each group of study?

During the Pandemic, some oral reading was added to ensure student participation, because 3D access to every student was not possible as well as visual measures of attention were not done as shown in Fig. 2. In this case, a weak internet connection provided by the internet servers was present for the lecturer and students in 2020 and later for viewing all video-cameras in Google Meet between 2021 and 2022. Utilization of online oral reading slides in their native language was asked of students in order to ensure a good attention level. But some students reported that this reading distracted them from the main subject of learning.

Anemia was not controlled for this study. It would be helpful to check anemia results through a longitudinal study. About 40% of the Peruvian population of the age of students have had anemia before the age of five (more than 10 years ago) and of them, a third of it is moderately way. Therefore, it should not be surprising that around a seventh of the students have had moderate anemia and it can affect their learning in some sensory modalities. For example, from a sample of 102 students at UNALM in Peru, it was found that 21.7% of women had anemia (Cárdenas-Quintana et al., 2019). At the National University of San Marcos in Peru; anemia was found in 4.5% of men and 44.1% of women (Ysihuaylas, 2017).

The Programme for International Student Assessment (PISA) indicator for students was not controlled. In the long term, the PISA indicators may have relevance. The results of PISA have forced the improvement of education in Peru. In recent years there has been an increase that would make less conceptual errors observed in students in the following 5 years (e.g. observed in Fig. S1). This limitation opens the question of what the changes observed in future university students will be qualitatively and quantitatively.

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Authors' contributions The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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Data availability Code, data, photographs, and hand and computer work were located at https://github.com/cmugruza/ArrayProcessing.

Declarations

Disclosure of potential conflicts of interest The author declares that he has no conflict of interest

Research involving human participants The study has been conducted in compliance with ethical standards for research involving human participants from the Ethical Committee and Professional School of the UNTELS. Analysis has been validated at UPSJB.

Informed consent No informed consent was collected for this study because I used aggregated data or data that are publicly available on request.

Competing interests The author declared that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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