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Front Pages

Athens Journal of Sciences

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Gregory T. Papanikos, President, ATINER.

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18-21 July 2022, Athens, Greece

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- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **20 June 2022**

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Net Aerial Primary Productivity Models for Alfalfa Varieties (*Medicago sativa* L.) Derived from the Red Vegetation Index

By Jose Luis Tiedemann[*]

The present study is aimed at quantifying and comparing the net aerial primary productivity (NAPP) of two alfalfa varieties (Medical sativa L.) by determining the Radiation Use Efficiency (Ɛ) for each variety, estimating the NAPP though the Red Vegetation Index and relating it to the quantified NAPP. Significant differences between the individual NAPP of each variety were not found: G969 = 1564 g dm m^{-2} and M901 = 1636 g dm m^{-2} ($T = 0.92$; $p>0.05$). The Ɛ of the G969 was 0.56 g Mj^{-1} while that of M901 was 0.58 g Mj^{-1}. Significant direct relationships between the quantified NAPP and that calculated using the Red Vegetation Index were found. The models obtained were: $NAPP_{G969} = 506.06x – 343.25$ ($R^2 = 0.88$; $p<0.001$) and $NAPP_{M901} = 420.28x + 37.82$ ($R^2 = 0.98$; $p<0.001$). The Ɛ values of the alfalfa varieties under study, determined at local level, reduce uncertainty when generating predictive models of productivity. The NAPP of alfalfa varieties can be non-destructively predicted using the Red Vegetation Index obtained by a reflex RGB digital camera.

Keywords: *radiation use efficiency, digital camera, canopy reflectance, RGB indices*

Introduction

Determining the net aerial primary productivity of the green vegetation in cattle raising activities is fundamental to make a decision at site level, particularly in assigning areas and managing grazing lands and livestock. The traditional measuring techniques, particularly the destructive ones (i.e., biomass harvesting or clipper, rising plate meter, compressed sward height, or a meter stick) are not only time consuming and increase costs but also highly tedious especially when the sampling area is increased (Gruner et al. 2019). Consequently, the spectral information supplied by remote sensing may provide a rapid and inexpensive means of estimating forage biomass and quality variables (Zhao et al. 2007, Gruner et al. 2019). In agriculture, there has been a rising demand in remote sensing due to its capabilities for collecting data involving less time, less labor and minor impact on the fields (Costa et al. 2020).

The Vegetation Index obtained from remote as well as near sensing, represents a combination or a filtering process of multiple spectral data sets to create a single value for each point in an image usually generated by a mathematical model (McKinnon and Hoff 2017). It is a good indicator of the ability for vegetation to absorb photo-synthetically active radiation and has been widely used by researchers

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to estimate green biomass. The close relationship between the net aerial primary productivity (NAPP) and the Vegetation Index made their use as potential productivity indicators possible (Tucker 1979). It was done using the Monteith's empirical model (1977) based upon the Radiation Use Efficiency (RUE = Ɛ) which is a useful tool for quantifying the seasonal biomass production without limitations of water, temperature or fertility.

Digital cameras, commercially accessible and available, are effective alternatives for estimating biophysical parameters (biomass and leaf area index) in a non-destructive way (Przeszlowska et al. 2006). They can be considered as proxy detection sensors of high spatial and time resolution, with a Cartesian system for capturing colors in the space, that is, red (R), green (G) and blue (B), where the RGB digital numbers provide a permanent and repeatable register of the plots at low cost and with high accuracy (Sonnetag et al. 2011, Sakamoto et al. 2012, Lussem et al. 2018). The intensity of the green and red reflectance becomes efficient choices to determine biophysical properties in agricultural crops (Gitelson et al. 2002). In this sense, either the Color or the Vegetation Indices synthetizes the information concerning the RGB brightness obtained by using digital cameras (Sonnetang et al. 2011). Several plant indices were created using just conventional RGB channels to make data collection more accessible (Costa et al. 2020).

Among the studies carried out using digital cameras it is worth mentioning those by Przeszlowska et al. (2006), which assessed the accuracy, precision, and relative labor costs of the traditional leaf area meter method and various indirect methods for measuring Green Area Index (GAI) on shortgrass prairie. GAI measured with a standard leaf area meter was compared to: 1) spectral vegetation indices calculated from multispectral radiometer data, 2) GAI obtained from laser point-frame measurements, and 3) green cover estimates derived from digital camera images. Ge et al. (2016) stated direct relationship between the 2G/(B+R) index and the estimated green area ($r = 0.95$), green matter ($r = 0.99$) and dry matter ($r = 0.95$) of corn (*Zea mays*). They concluded that the area estimated using the index and related to destructive measurements is a good estimator of green matter, dry matter and leaf area in early vegetative states ($r = 0.95$). Jáuregui et al. (2018), using canopy software, related light interception and the NAPP in alfalfa crops by the R/G, B/G and 2G-R-B Vegetation Index and reported the coverage percentage or foliage green area index. They obtained significant direct relationships in spring and summertime ($R^2 = 0.86$; $p<0.05$) and in fall and wintertime ($R^2 = 0.77$; $p<0.05$).

Based on the above and tending to get local information, this study aims at quantifying the net aerial primary productivity of two varieties of alfalfa (*Medicago sativa* L.), determining the Radiation Use Efficiency in each variety, estimating the NAPP using the Red Vegetation Index derived from the digital camera, and relating it to the quantified NAPP.

Methodology

Study Area

The test was carried out at the Silviculture and Forest Management Institute (Lat -27.88; Long -64.25), Forest Sciences Faculty (FCF), National University of Santiago del Estero (UNSE), located at El Zanjon, Province of Santiago del Estero, Argentina (Figure 1).

Figure 1. *Left: Argentina and the Province of Santiago del Estero (in Gray) Center: Province of Santiago del Estero and El Zanjon (Red Star) Right: Test Location (Red Circle), the Silviculture and Forest Management Institute, FCF, UNSE (Lat -27.88; Long -64.25)*

Source: The National Geographical Institute and Google Earth.

The climate data of the area under study (Table 1) was provided by Santiago del Estero Aero Station (Lat -27.76; Long -64.32) of the Weather Information Center of the National Weather Service (2020).

Table 1. *Climate Variables of the Area under Study Correspond to 2018–2019, being TMED: Mean Temperature, PPMEAN: Mean Precipitation, EVT-P: Potential Evapotranspiration and HR: Relative Humidity*

2018–2019	TMED °C	PPMEAN mm	EVT-P mm day^{-1}	Wind Km h^{-1}	HR. %
AUG	14.39	2	2.12	5.96	54.3
SEP	21.72	12.30	3.56	6.17	50.90
OCT	22.11	44.70	3.59	4.93	54.80
NOV	25.04	66.7	5.02	6.51	59
DEC	26.05	114.2	5.16	5.64	62.7
JAN	26.57	134.8	4.97	5.06	66.8
FEB	24.79	100.6	4.61	4.62	70
MAR	24.84	91.1	4.67	3.68	74.2
APR	20.43	35.9	2.62	3.16	76.6
MAY	16.33	17.2	4.90	2.61	74.5
JUN	13.31	6.6	5.13	2.75	73.2
JUL	12.69	3	4.32	3.63	63.6

The soil of the study area is Torriortentic Haplustoll with A1, AC C1 and IIC2 horizons, without depth and drainage limitations (Angueira 2015). Table 2 shows modal soil profile (Lat -27.864; Long-64.219).

Table 2. *Modal Soil Profile of the Area under Study*

Horizon	A1	AC	C1	IIC2
Depth (cm)	0–23	23–64	64–130	130–150
Clay (%)	7	6	6	5
Slime (%)	34	35	37	51
Sand (%)	59	59	57	44
Texture	Sandy loam	Sandy loam	Sandy loam	Silty loam
Organic Matter %	1.1	0.5	0.3	0.2
Organic Carbon (%)	0.7	0.3	0.2	0.1
Total Nitrogen (%)	0.1	0.1	0	0
Relation C/N	7	4	6	6
Phosphorus (p.p.m)	0.9	2	1	1
CO_3Ca (%)	0	0	3.1	2.3
pH	7.3	8	8.1	8
Calcium (meq/100 g)	6.9	8.3	-	-
Magnesium (meq/100 g)	1.2	1.2	-	-
Sodium (meq/100 g)	0.2	0.4	0.5	1.1
Potassium (meq/100 g)	0.9	0.6	0.6	0.5
CEC (meq/100 g)	8.7	9.6	8.6	8.1

Source: Angueira 2015.

Quantified Net Aerial Primary Productivity

On April 15th 2018, two commercial varieties of alfalfa, totally randomized design in 1.5 m^2 plots with eight replications per variety^{-1}, were implanted (*Medicago sativa* L.): G969 (www.gapp.com.ar) and Magna 901 (www.forratec.com.ar). Both varieties belong to latency Group 9. The average density effectiveness was 350 plants per square meter. To minimize the factors affecting pasture biomass productivity and, consequently, the RUE (Monteith 1977) they were irrigated and fertilized while sowing with 100 kg ha^{-1} of NPK (16.7.15). Monthly post-harvest irrigation of approximately ~50 mm irrigation^{-1} was carried out. The green biomass or the net aerial primary productivity of each variety was harvested and weighed at the preflowering stage, and dried afterwards. Annual Net Aerial Primary Productivity of each variety was temporarily integrated and expressed in grams of dry matter per square meter (g dm m^{-2}). The means of the NAPP (hopes) between varieties (distributions) were evaluated using the T-test for independent samples (Di Rienzo et al. 2011).

Camera Technical Programming and Photography

The images were obtained using a D7100 Nikon Digital Reflex Camera (Nikon Corporation, Tokyo, Japan) with a built-in CMOS image sensor of 23.5 x 15.6 mm, 24.1 real megapixels, an AF-S NIKKOR lens of 18-300 mm f/3.5-5.6G EDVR. The size of the selected photogram was 2.304x1,536 pixels in RAW format (Nikon Electronic Format), 14 bit depth, 24 bit RGB resolution (Ahrends et al. 2009). The camera was set up in automatic mode and an ISO 200 sensibility (Sakamoto et al. 2012).

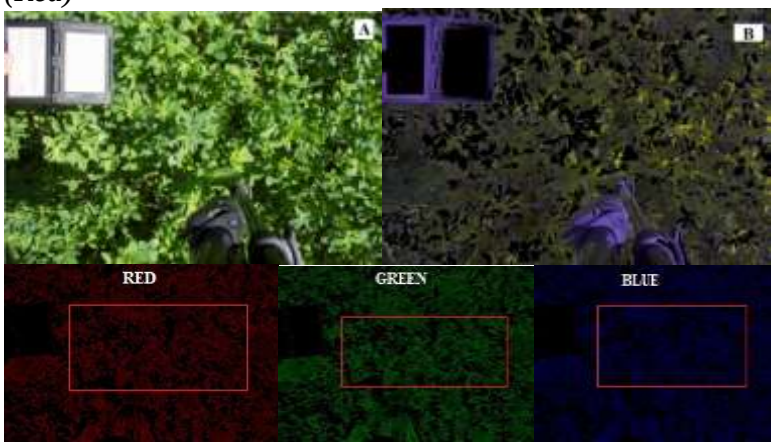
The camera was geometrically set up onto a vertical tripod using bubble levels and angle graduation at 1m above top of the canopy; the sensor was oriented to each plot center with a 0° inclination angle (Tiedemann 2019) (Figure 2). The images were shot previous to harvest in cloud-free days at approximately solar noon between 10.00 AM and 2.00 PM (Inoue et al. 2015). The white balance of the images was adjusted using the 18% Gray Balance reflectance card (X-Rite corporation) placed at the central area of every plot (Inoue et al. 2015) (Figure 2).

Image Processing and Digitization

The calibration of the camera sensor was done using a calibration profile of DGN sensors generated from a standard color reference image Color Checker Passport (X-Rite, Incorporated).

All the images were linearly adjusted in spectral terms using the sensor calibrating profile (DGN), the Adobe Camera Raw software and saved as a TIFF (Tagged Image File Format) document standardized at 8 bit (Min 0; Max 255). The images were classified using the IsoData classifier available in the ImageJ software (Ferreira and Rasband 2016), assigning value one (1) to the green aerial forage biomass, i.e. the photosynthetically active vegetation (Baret et al. 2010), and zero (0) to the remainder background. From the resulting binary image, digital numbers were extracted using the digital sampling polygon (Sonnetag et al. 2011) (Figure 2).

Figure 2. *Top: A) RGB Image at 0° and 18% Gray Balance Reflectance Card B) Binary Image of A. Bottom: Red, Green and Blue Bands with Sampling Vectors (Red)*



The Red Vegetation Index

The digital number of the RGB images was strongly influenced by the scene lighting. In order to suppress such an effect, a non-linear transformation of RGB to the *r, g* and *b* color coordinates (Gillespie et al. 1986, Woebbecke et al. 1995) was made. The chromatic coordinates *r, g* and *b* were obtained from equation 1:

$$r = R^*/ R^*+ G^*+ B^*, \quad g = G^*/ R^*+ G^*+ B^*, \quad b = B^*/ R^*+ G^*+ B^* \quad (1)$$

where R*, G* and B* stand for the normalized RGB values (0-1) defined as R* = R/Rm; G* = G/Gm; B* = B/Bm, being R, G and B the digital levels of the photosynthetically active vegetation of the study area, respectively, whereas Rm = Gm = Bm = 255 were the tonal maximum value of the (8 bit) primary colors (Gillespie et al. 1986; Woebbecke et al. 1995). In this study, the red color coordinate was used as the Red Vegetation Index (Tucker 1979).

The Predicted Net Aerial Primary Productivity

Many studies analyzed the direct relationship between the Normalized Difference Vegetation Index (NDVI) and the NAPP (Tucker 1979) expressed by equation 2 as:

$$NAPP_{Predicted} (g\ dm\ m^{-2}) = \mathcal{E} * \sum NDVI_{ij} \quad (2)$$

By replacing the Normalized Difference Vegetation Index in Equation 2 by the Red Vegetation Index, Equation 3 results as:

$$NAPP_{Predicted} (g\ dm\ m^{-2}) = \mathcal{E} * \sum VI\ Red_{ij} \quad (3)$$

where *i* stands for the integrated Red Vegetation Index of each cutting and variety of the growth season *j* (i.e., between April 2018 and February 2019).

The values for the Radiation Use Efficiency ($\mathcal{E}$) (g Mj^{-1}) in the study area are scarce because they were obtained for each variety using the Monteith's Model (1997) of Equation 4:

$$\mathcal{E} (g\ Mj^{-1}) = NAPP_{Quantified} (g\ m^{-2}) / PAR\ (Mj\ m^{-2}) \quad (4)$$

where NAPP stands for the quantified aerial biomass productivity, annually integrated for each replicate and variety. The annual average incident solar radiation over the study area was obtained from maps developed by Righini and Grossi Gallegos (2011). Photosynthetically active incident radiation (PAR) over the foliage is considered a constant fraction of 48% of incident radiation on the border of the atmosphere (Fensholt 2003).

The Quantified vs. the Predicted NAPP Relationship

The quantified NAPP (dependent variable *y*) and the predicted NAPP (independent variable *x*) were related by means of the simple linear regression method (α 0.05). The lineal models were tested based on the best adjustment of the coefficient of determination (Di Rienzo et al. 2011).

Results

Net Aerial Primary Productivity of the Varieties

Seven harvests of each alfalfa variety were made between September 15, 2018 and February 4, 2019. Significant differences were not found in the NAPP between varieties (T = 0.92; p>0.05). The average NAPP of the G969 variety was 1564 g dm m^{-2} while that of the M901variety was 1636 g dm m^{-2}. The NAPP of the G969 variety obtained in this study fluctuates in the range of the average values obtained for the same variety by Cornachione (2018) at Estacion Experimental Agropecuaria Santiago del Estero of Instituto Nacional de Tecnología Agropecuaria (EEA INTA SDE) in the following periods: 2014/2015 = 2157 g dm m^{-2}, 2015/2016 = 1802 g ms m^{-2}, 2016/2017 = 1926 g dm m^{-2} and 2017/2018 = 862 g dm m^{-2}.

In the province of Cordoba, Argentina, the NAPP for the G969 variety estimated by Arolfo and Olivo (2018) was the following: 2014/2015 = 1344 g dm m^{-2}, 2015/2016 = 1588 g ms m^{-2} and 2016/2017 = 919 g dm m^{-2}. Similarly, Gallego et al. (2018) determined that the NAPP of the G969 variety was higher than 2000 g dm m^{-2} in the irrigated valleys of Rio Negro, Southern Argentina.

The EEA INTA SDE's network of cultivars did not report yield results of the M901 variety in the periods analyzed.

However, the NAPP obtained in this study of the M901 variety (1636 g dm m-2) is in the range of average values of alfalfa varieties determined by the EEA INTA SDE. The average NAPP values estimated in the periods 2014/2018 were as follows: 2014/2015 = 2222 g dm m^{-2}, 2015/2016 = 1884 g ms m^{-2}, 2016/2017 = 1980 g dm m^{-2} and 2017/2018 = 980 g dm m^{-2} (Cornachione 2018). Otero and Castro (2019) reported that the seasonal NAPP of intermediate-latency alfalfa in the period 1997/2011 in the Southeast of Uruguay was distributed as follows: Autumn = 3.902 g dm m^{-2}, Winter = 1.872 g dm m^{-2}, Spring = 4.024 dm m^{-2} and Summer = 5.381 dm m^{-2}.

Radiation Use Efficiency ($\mathcal{E}$)

The average Radiation Use Efficiency of the G969 variety was Ɛ = 0.56 g Mj^{-1}, being the maximum Ɛ = 0.64 g Mj^{-1} and the minimum = 0.43 g Mj^{-1}. The average Radiation Use Efficiency of the M901 variety was Ɛ = 0.58 g Mj^{-1}, being the maximum Ɛ = 0.66 g Mj^{-1} and the minimum = 0.51 g Mj^{-1}. Ɛ values locally

obtained become relevant since this variable creates greater uncertainty when estimating the NAPP using the Monteith model (Fensholt et al. 2003).

Pereyra et al. (2019) determined the $\varepsilon = 0.83$ g Mj^{-1} of the Mayaco variety latency 7 in the city of Rio Cuarto, Cordoba, Argentina.

In turn, Akmal et al. (2011) found significant differences in the Radiation Use Efficiency of fifteen alfalfa lines. They observed that alfalfa line Flewish-pop was a high resource capturing with 0.20 g dm Mj^{-2} PAR absorbed among the other line when compared in the group, followed by line Gramma-2 with about 0.18 g dm Mj^{-2} PAR absorbed. The lowest RUE was recorded for No. 12-991 which was approximately 0.03 g dm Mj^{-2} PAR absorbed.

According to Druille et al. (2019), their objective was to quantitatively synthesize, through a meta-analysis, the variation of RUE of forage resources and its main controls. They gathered 496 RUE values and assessed their variation according to genotype, resource availability and phonological stage. Mean RUE was 1.93 ± 1.2 g dm Mj^{-2} PAR absorbed. This large variability implies a challenge to select RUE values as input to estimate productivity through plant-growth models, such as those based on remote sensing, but also highlight the margin for increasing RUE through breeding and management practices.

The Quantified-Predicted NAPP Relationship

Significant direct relationships were found in the correlations between the quantized NAPP and the predicted one by the Red Vegetation Index for each variety (Figures 3 and 4). The resulting models are introduced by Equations 5 and 6 below:

$NAPP_{G969} = 506.06 * x - 343.25$ ($R^2 = 0.88$; $p<0.001$) (5) (Figure 3),

$NAPP_{M901} = 420.28 * x + 37.82$ ($R^2 = 0.98$; $p<0.001$) (6) (Figure 4).

Figure 3. *The G969 Variety Linear Regression Model between the Estimated and the Predicted NAPPs (g dm m^2)*

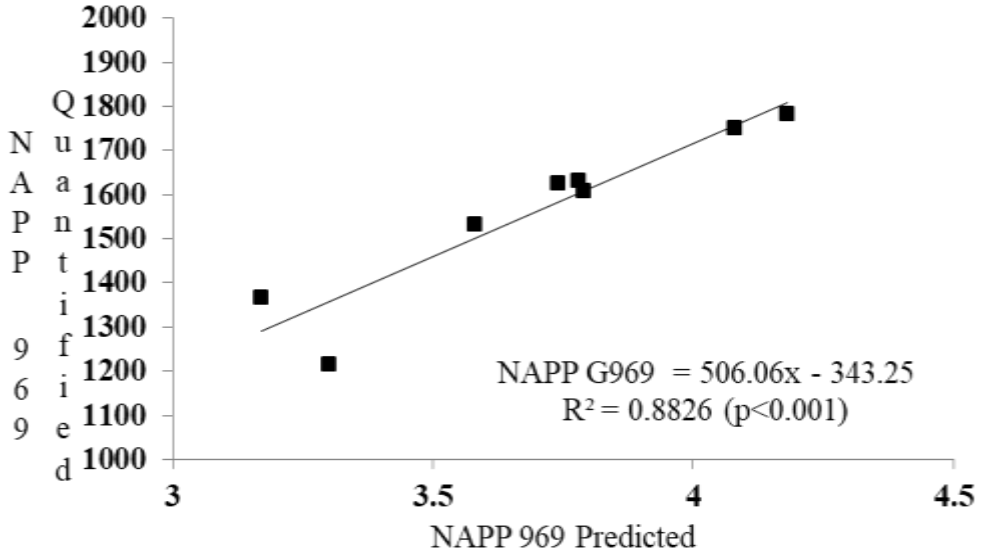
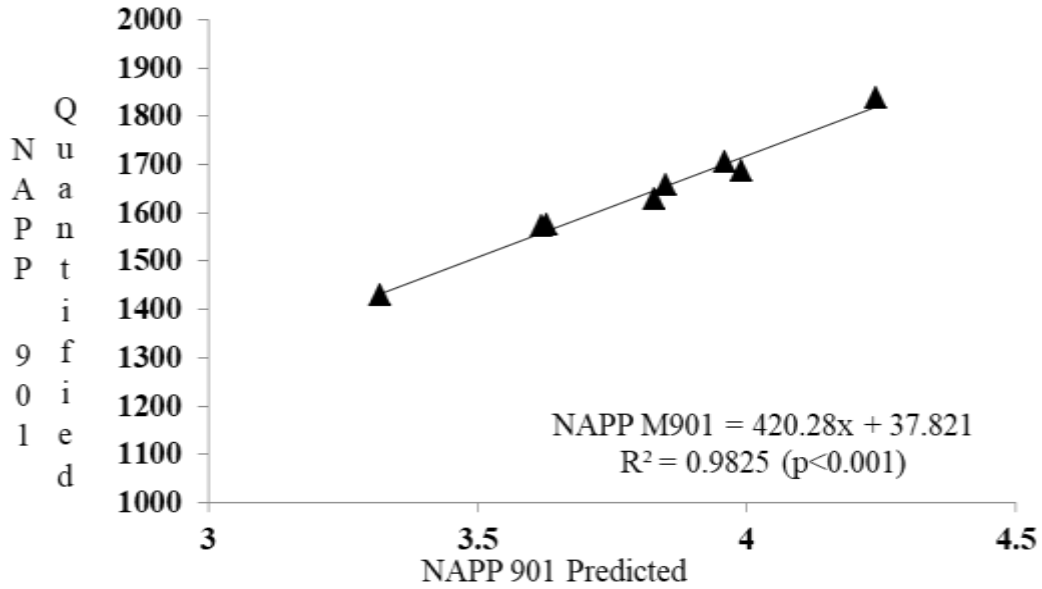


Figure 4. *The M901 Variety Linear Regression Model between the Estimated and the Predicted (Ɛ* IV Red) NAPPs (g dm m^2)*



In preliminary studies, Tiedemann (2018a) found significant inverse relationships (R^2 = 0.81, r = -0.92; p<0.01) between the integrated NAPP of the G969 alfalfa and the RGB Vegetation Index (i.e., Red, REI, T and SUM).

Grüner et al. (2019) developed prediction models for dry matter yield in temperate grassland based on the canopy height data generated by RGB imaging. The multi-temporal study compared the remote sensing technique with two conventional methods, i.e., destructive biomass sampling and ruler height measurements in two legume-grass mixtures with red clover (*Trifolium pratense* L.) and lucerne (*Medicago sativa* L.) in combination with Italian ryegrass (*Lolium multiflorum* Lam.). The results showed that yield prediction by RGB imaging provided similar accuracies across all treatments (R^2 = 0.59–0.81) as the ruler height measurements (R^2 = 0.58–0.78). Bendig et al. (2014) estimated above-ground biomass and fresh and dry biomass on a summer barley test site with 18 cultivars and two nitrogen (N)-treatments using the plant height from crop surface models. The crop surface models were derived from red, green, blue (RGB) images. Five models for above-ground fresh and dry biomass estimation were tested by cross-validation. Modelling biomass between different N-treatments for fresh biomass produced the best results (R^2 = 0.71). Schirrmann et al. (2016) monitored the biophysical parameters and nitrogen status in wheat crops with low-cost imagery. The correlations between the biophysical parameters and image variables were highly significant, the regression models calculated with the principal components of the image variables yielded R^2 values between 0.70 and 0.97.

Lussem et al. (2018) evaluated the robustness of RGB-based vegetation indices to estimate dry matter forage yield on a recently established experimental grassland site in Germany. They selected RGB-based vegetation indices which were tested to predict dry matter yield and compared to three indices from the

visible to near-infrared domain calculated from spectroradiometer measurements. The results showed a correlation of forage yield with RGB-based VIs such as the NGRDI index (NGRDI = green-red/green+red) (developed by Tucker 1979) with R^2 values of 0.62. Hunt et al. (2005) observed a linear correlation of NGRDI with alfalfa, corn, and soy biomass, but also observed saturation effects of the predictor variable for higher biomass yields.

Similarly, Fernandez et al. (2019) evaluated the capacity of vegetation indices formulated using blue (B), green (G), red (R) and near-infrared (NIR) bands obtained with a consumer grade camera to assess wheat N status. RGB indices and NDVI obtained with a consumer-grade camera showed comparable capacity at assessing chlorophyll content and predicting both crop biomass and grain production at harvest as those obtained with a spectroradiometer. The RGB indices and NDVI were found to be related to both crop biomass and grain production at harvest ($r>0.80$, $p<0.01$).

Tiedemann (2018b) found significant direct relationships ($p<0.01$) between the NAPP of wheat varieties and the Total and Red indices; the R^2 varied between 0.92 and 0.96. Following the same study line, Tiedemann (2019) detected significant ($p<0.01$) direct relationships between the Red, REI, T and SUM Vegetation Indices taken at 0° and 45° and the NAPP of wheat varieties. The resulting linear models at a 0° angle showed an R^2 that ranged from 0.75 to 0.67, while at 45°, the R^2 varied between 0.67 and 0.70.

Discussion

The average NAPP obtained from both varieties oscillates in the range of the NAPP average values of 27 alfalfa varieties in the 8, 9 and 10 latency groups (recommended for the Argentine Northwest) determined by the EEA INTA SDE. The average NAPP during 2010/2018 was 1995.9 g dm m^{-2} (Cornachione 2018). It should be noted that alfalfa cultivars yield has been severely affected in recent decades by extreme climatic anomalies, since the genotype/environment interaction conditioned the expression of cultivars, especially cultivars without winter dormancy (Spada 2007).

Since the Radiation Use Efficiency $\mathcal{E}$ values of alfalfa (*Medicago sativa* L.) are scarce in the region, the results obtained here become relevant since, in accordance with Baret et al. (2010), they allow to lower uncertainty in the generation of predictive models. According to Collino et al. (2007) variations of Ɛ are to be attributed to factors such as variety, radiation and temperature regimes, direct-diffuse radiation rate and differences in the partition between foliage and storing organs (crown and roots). In turn, Druille et al. (2019) informed that the Ɛ values mostly respond to the genotype and directly or indirectly to resource management and availability. Brown et al. (2006) quantified the influence of the seasonal variation on the solar radiation, temperature and the biomass partition of irrigated alfalfa and found a lineal relationship between the NAPP of the alfalfa ($R^2 = 0.93$) and the total intercepted radiation, the Ɛ ranged between 0.29 g Mj^{-1} and 1.09 g Mj^{-1}. The authors concluded that the NAPP is highly affected by the

variation of the incident solar radiation (seasonality) and by the air temperature in temperate environments. In this sense, Bat-Oyun et al. (2012) determined for natural pastures in semiarid settings a wide range of Ɛ (0.23 g Mj^{-1} – 1.06 g Mj^{-1}) that was affected by water and thermal stress, together with a maximum Ɛ value of 2.34 g Mj^{-1} without thermal and water stress. At the same time Garbulsky (2010) concluded that the spatial variability of the Ɛ can be better explained by the annual precipitation than by the type of vegetation.

At a regional level, Collino et al. (2005) determined in Cordoba, Argentina, that the Ɛ for the Monarca SP INTA crop (group 8 of dormancy) was of 0.81 g Mj^{-1} in fall, 0.62 g Mj^{-1} in winter, 1.28 g Mj^{-1} in spring and 1 g Mj^{-1} in summer. The Ɛ of the Victoria SP INTA crop (group 6 of dormancy) fluctuated between 0.6 g Mj^{-1} and 1.3 g Mj^{-1}, decreased linearly below 21.3°C and stabilized in 1.3 within an average range of optimal temperatures of 21.3 °C and 26.5 °C. The authors concluded that such a wide range of Ɛ occurred because of the high variation in the annual temperatures and the distribution of photo-assimilates. Pece and Cangiano (2002) using a similar crop, found the same trend in the southeast of Buenos Aires, Argentina, though with values of Ɛ oscillating between 1.1 g Mj^{-1} and 1.97 g Mj^{-1}.

Because of the arid conditions of the study area, and of NW Argentina in general, the edaphic water availability appears as the limiting factor; without such a limiting factor, all the varieties of alfalfas respond with a high Ɛ in both fall and summer. However, in accordance with Collino et al. (2007), the Ɛ is affected by low temperatures and photo-assimilates mobility in fall and winter.

The models found had a high ability to predict the NAPP of both varieties, the coefficient of determination (R^2) of both models is high (Equations 5 and 6), however, that of the M901variety is much higher. What would be the reason for this difference if both varieties were treated under similar environmental conditions (irrigation, fertilization, seasonality, sanity and management)? At the time the photogram was shot, the solar lighting geometry, the storage format of the photogram, the camera nadir position, the adjustment of the white balance of the images, the sensor calibration, and the methodology in the preparation of the Index were considered. Therefore, such difference should be related to the combined effects of the whole-canopy structure of the varieties, such as foliage geometry and leaves distribution, stem characteristics, that affect the patterns of scattering and absorption and consequently the Vegetation Index (Ollinger 2011, Grüner et al. 2019, Biriukova et al. 2020). In this sense and according to their respective producers, the M901variety has a semi-erect growth habit while the G969 shows an erect one, and hence both varieties use the space in a different way. The semi-erect M901 variety shows a green leaf area larger than that of the erect variety when the photogram is taken at a 0° angle. Results of yield prediction by RGB imaging obtained by Grüner et al. (2019) demonstrated an improved robustness when increased canopy height variability occurred due to extreme weather conditions. It became apparent that morphological characteristics of clover-based canopies ($R^2 = 0.75$) allow a better remotely sensed prediction of total annual yield than for lucerne-grass mixtures ($R^2 = 0.64$), and that these crop-specific models cannot be easily transferred to other grassland types. In turn, Inostroza et al. (2018) found significant inverse relationships with the Lab-b ($r = 0.56$, $p<0.001$), HUE (r

= 0.58, p<0.001), Luv-v (r = 0.55, p<0.001) and green area (r = 0.36, p<0.01) indices when evaluating the phenotypical relationship between the Vegetation Indices derived from the RGB digital camera and the NAPP of sixty-three populations of alfalfa. The authors preliminarily concluded that the RGB digital camera-derived Vegetation Indices are phenotypically associated to the NAPP. In the same way, Mizunuma et al. (2014) recommend using hue as a colour index for tracking different stages of leaf development. However, it should be noted that Stevens et al. (2007) do not recommend utilizing indices derived from the conversion to other values of color in the space as HSB (hue, saturation and brightness) because of their high inaccuracy.

Conclusions

The NAPP values obtained for both varieties represent an original contribution to this field of study, especially the M901 variety NAPP.

The values for the Radiation Use Efficient $\mathcal{E}$ of the alfalfa varieties under study, determined at local level, gain relevance due to the absence of locally estimated values. These reduce uncertainty when predictive models of productivity are generated.

The net aerial primary productivity (NAPP) of alfalfa varieties can be quantified in situ in a non-destructive manner using the Red Vegetation Index. The strength of the Index lies in the rigorous methodology used for its creation and because it was derived from a reflex RGB digital camera.

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Mean Daily Variability of Energy Fluxes Above Alexandria Eastern Harbor

By Maged M.A. Hussein[*]

Mean daily variability of latent heat (E), sensible heat (H), net long wave (Lw_{net}), net short wave, and net flux of surface heat balance were estimated from hourly sea surface water temperature (SST) and meteorological time series obtained for three months during summer season (2019) in Alexandria Eastern Harbor (AEH), Egypt. Latent and sensible heat were not in phase and had their maximum 181.12 W/m^2 (5:00 PM), 16.5 W/m^2 (5:00 AM) and minimum 103.64 W/m^2 (8:00 AM), -12.14 W/m^2 (3:00 PM), resulting in Bowen ration of -0.11 and 0.09, respectively. The loss of heat by evaporation therefore predominates than sensible heat utilized to warm surface atmosphere. The instability of the atmosphere was existing nearly most of the time period, rising exchange coefficients of sensible and latent heat flux by about 24.26% over estimated neutral values (from 1.15 × 10^{-3} to 1.43 × 10^{-3}). Mean Lw_{net} changed from 165.63 at early morning to 173.52 W/m^2 at late afternoon, point out its significant importance in the total balance of heat flux of eastern harbor surface. Latent heat flux and Lw_{net} were positive (energy losing from eastern harbor), throughout the day. The daily average of net energy budget (S) was 38.52 W/m^2; daytime gain exceeded nighttime loss, with consequent heating the eastern harbor. Qualitatively, daily variations of net energy budget (S) were nearly consistent with time delay to the variability of sea surface temperature, indicating the predominant role of the heat budget of the surface layer in modulating surface temperatures of the Eastern Harbor.

Keywords: *heat flux, shortwave, long wave, latent heat, sensible heat, Eastern Harbor*

Introduction

The main meteorological factors like the wind speed and forthcoming solar radiation contribute to the increasing of the mixed layer whilst water movement is the cause of temperature changes (hydrological processes) (Schertzer 1987). Energy fluxes across the surface of water body affect the water balance in addition to regulate or adjust heat storage (Hussein 2019). The conditions of atmospheric stability over the surface water can affect the heat fluxes of evaporative and convective from the surface water (Hussein 2019).

The heat fluxes (latent and sensible) represent the heat interchange between the atmosphere and ocean (Larid and Kristovich 2002). The heat budget of water body (lake, harbor, etc.) is controlled or governed by interaction with the above layer of the atmosphere. These interactions obviously are affected by the stability of atmosphere over the surface water (Abbasi et al. 2017, Verburg and Antenucci

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2010). The atmosphere over the surface water is unstable when the value of Obukhov stability length is non-positive (Abbasi et al. 2017, Verburg and Antenucci 2010, Brutsaert 1982). The air and water temperature (surface) differences can be utilized as an evidence of stability (Derecki 1981, Croley 1989, Verburg and Antenucci 2010). The loss of heat from surface water by the sensible and latent heat action is reduced when the atmosphere over it is stable and enhanced when the atmosphere over it is unstable (Brutsaert 1982). Unstable conditions of the atmosphere over water body can keep on long periods (Rouse et al. 2003). Lakes, harbors or any water body more extreme fluctuated from quite stable to quite unstable consequent to in general lower wind speeds and as well consequent to the maximal cooling and heating by the circumambient land (Abbasi et al. 2017).

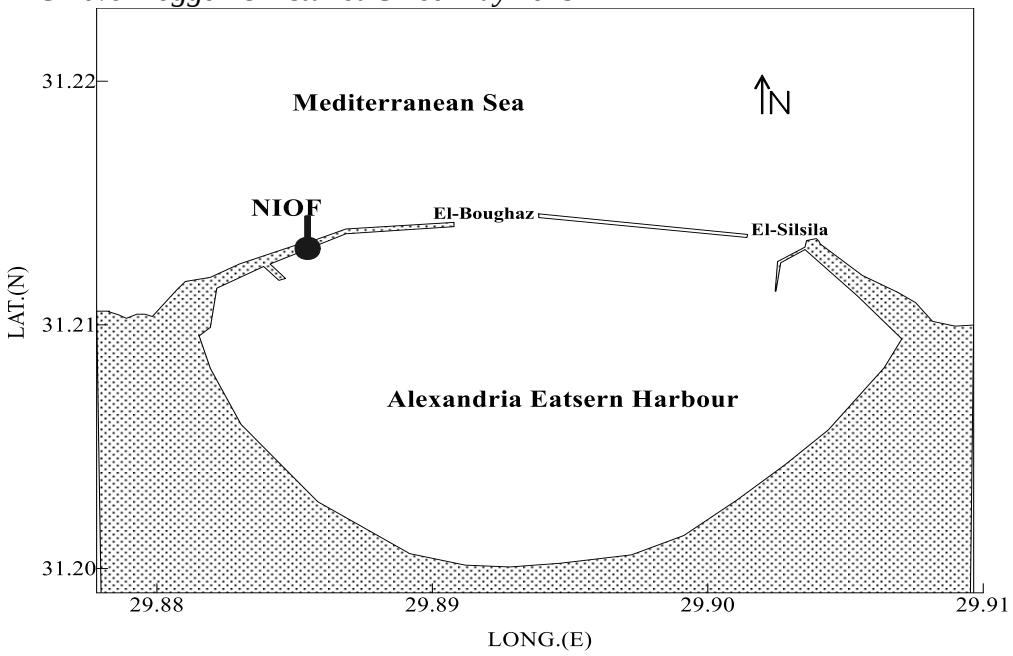
The instability of the atmosphere above Alexandria Eastern Harbor occurred 96.09% of the time through the time period (6/6/2010 to 16/2/2011) and consequence in 24.55% rises in the evaporation in comparison to the neutral condition. The results denote that an unstable condition of the atmosphere has a significant or considerable impact in rising evaporation as well the flux of sensible heat (Hussein 2018).

The main objective of the present study was to collect and the necessary data to estimate the components of heat flux (latent, sensible, and long wave) and the net shortwave radiation and to determine the net surface heat flux balance. In this study, establish test the magnitude and relative role played by each flux component in the overall net surface heat balance and their average daily variability. Also, discuss the influence of the net heat flux on the observed daily variability of the surface layer temperature. Particular attention was given to the role of the atmospheric boundary layer (ABL) instability in strengthening the turbulent fluxes.

Study Area

Alexandria Eastern Harbor (AEH) (Figure 1) is a shallow, nearly enclosed and semicircular basin. It occupies nearly a central part of Alexandria coast with an area of about 2.80 km^2. AEH is linked to the Mediterranean Sea via two outlets or openings: the main central outlet is called El-Boughaz and the second outlet is called El-Silsila. The slopes of the Harbor seabed gradually seawards, with an average depth of 5 m into the AEH and a reach to maximum depth of 13 m at the extreme eastern corner of El-Boughaz (Hussein and El-Geziry 2104, Hussein 2018, Hussein 2019).

Figure 1. *The Location of NIOF at Alexandria Eastern Harbour (AEH) Where the LTC Level Logger is Installed Since May 2019*



Material and Methods

Dataset

The hourly meteorological parameters measurements of AEH such as air temperature T_a (°C), relative humidity R_h (%), wind speed U (m/s), and atmospheric pressure P (hpa) were made for three months (92 days) began 1/6/2019 and ended 31/8/2019 resulting in 2208 hourly data points per time series have been utilized to estimate the fluxes of latent and sensible heat of AEH. The Meteorological data has been supplied by the Alexandria Air Port meteorological station and acquired by means of the following website: https://www.wundergrou nd.com/history/daily/eg/alexandria/HEAX/date/2019-06-01.

Hourly sea surface temperature (SST) has been obtained from the device namely: (LTC – Level Logger), Temperature and Conductivity Logger immersed about 1.5 m under the water surface in AEH.

Methodology

The fluxes of latent and sensible heat were calculated utilizing the Method of Bulk Aerodynamic, taking into consideration the dependence of the transfer coefficients on the stability of atmospheric boundary layer (ABL) (Amorocho and DeVries 1980, Imberger and Patterson 1990, Verburg and Antenucci 2010, Lorenzzetti et al. 2015). The fluxes of latent (E) and sensible heat (H) W/m^2 were calculated from the following equations:

$$E = \rho_a L_v C_e U(q_s - q_z) \quad (1)$$

$$H = \rho_a C_a C_h U(SST - T_a) \quad (2)$$

Where air density is ρ_a (kg/m^3), latent heat of vaporization is L_v (J/kg), specific heat of air is C_a (°C), specific humidity at saturation pressure at SST is q_s in (kg/kg), and specific humidity of air at height Z is q_z (kg/kg). The coefficients of exchange C_e and C_h are supposed to be equal (Zeng et al. 1998).

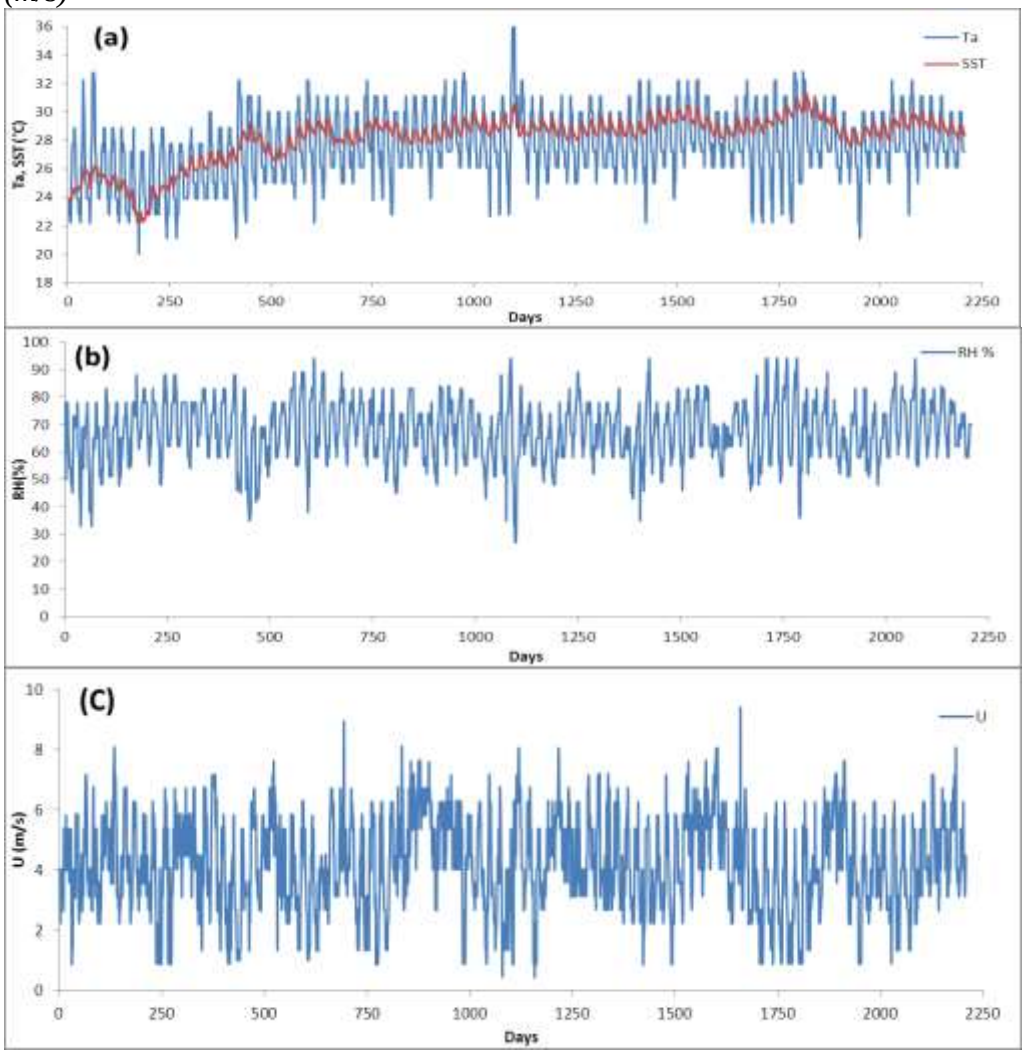
I have followed steps that have been used by Lorenzzetti et al. (2015) to calculate the following quantity: (1) Obukhov stability length L (m), (2) neutral transfer coefficients of atmospheric stability C_{dn}, C_{en} and C_{hn}, that are utilize to obtain initial values for latent heat (E_n), sensible heat (H_n) and u_* (friction velocity m/s), (3) functions of atmospheric stability (Ψ), that depend on stability parameter ($\xi = Z/L$), (4) E, H, C_e and C_h were estimated after adjusted the coefficients, (5) net flux of long wave radiation (Lw_{net} w/m^2) was calculated as the difference between the net incident (Lw_{inc} w/m^2) and emitted (Lw_{emi} W/m^2) long wave radiation, here cloud cover fraction supposed equal to 0 because there is seldom or no clouds in summer season in the study area. Also, I have followed method that has been used by Miyakoda and Rosati (1988) to estimate the values of short wave radiation.

Results

Meteorology

An evident signal was illustrated in the hourly values of relative humidity (R_h), air temperature (T_a) and wind speed (U); sea surface water temperature (SST) likewise displayed a cycle pattern, but of quit smaller value than that for air (Figure 2). About 60.86% of the available data, the SST was greater than T_a, unstable condition of atmospheric boundary layer (ABL). Always in afternoon, air temperature (T_a) was larger or warmer than SST in few degrees. In case of T_a lower than SST during the day, it basically was enhancing the flux of sensible heat. Lower magnitudes of daily shortwave were happened directly after sunrise and before sunset. During afternoon, maximum radiation of shortwave varied between 837-1054 W/m^2. Relative humidity varied between 33-66% and wind speed hourly values varied between 1-8 m/s.

Figure 2. *Hourly Values of (a) SST at 1 m Below the Eastern Harbor Water Surface and Air Temperature (°C), (b) Relative Humidity (%) and (C) Wind Speed (m/s)*



To calculate the daily cycle, each hour has been averaged of the 24 hours (day) utilizing the identical hourly magnitudes observed of the total period (Figure 3), which decreased the large frequency and the original weather data variability.

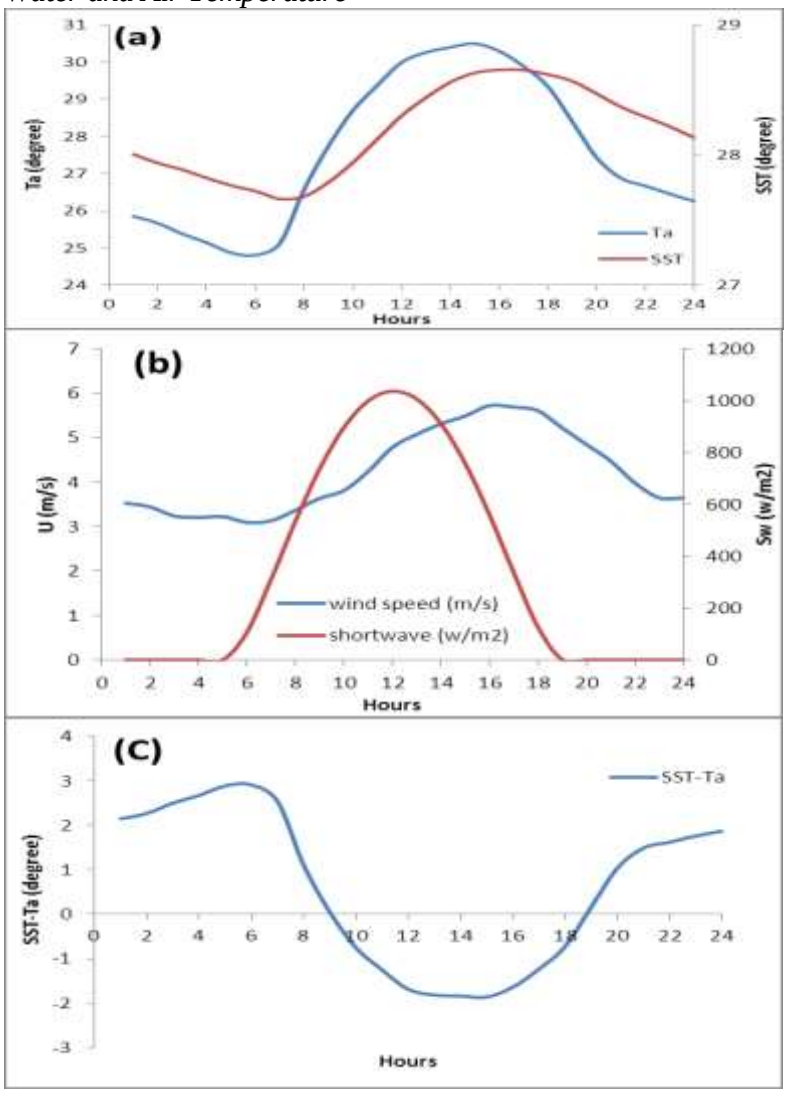
The mean daily of air temperature above the Eastern harbor displayed a temperature range of 5.68 °C, with a minimum of 24.81 °C between 05:00 and 06:00 AM, after having declined from its maximum magnitude of 30.49 °C observed at 15:00 PM at midafternoon (Figure 3a). The temperature of surface water observed a weaker but identical behavior, lagging behind air temperature by about 1 hour, with a range of 4.77 °C (Figure 3a). Air was colder than water after sunset until 8:00 AM; a little inversion was showed only at 15:00 PM, when T_a was maximum and higher than SST by about 1.84 °C. From 05:00 to 06:00 AM (end of the nighttime) air was colder than water at a maximum of -2.91 °C. This average cycle pattern of water and air temperature supports the scene presents in

the actual or authentic data that the atmospheric boundary layer (ABL) over eastern harbor was unstable nearly most of the day.

Average wind speed U was comparatively weak. There is no significant modification was viewed along the day. From about 6:00 to 7:00 AM, wind value was reach to its minimum of 3.09 m/s; from 9:00 AM to 16:00 PM it increase rapidly to a reach it is maximum of 5.71 m/s; and from 16:00 PM to 23:00 PM it decrease again to 3.64 m/s (Figure 3b).

Maximum shortwave radiation (hourly mean) was about 1036 W/m^2, with sunrise about 00:06 AM and sunset at about 18:00 PM (Figure 3b). Figure 3C represents the difference of air and surface water temperature, SST was higher than T_a from 19:00 PM to 9:00 AM and T_a was higher than SST from 10:00 AM until 18:00 PM.

Figure 3. *Mean Daily Variability of (a) SST and Air Temperature (T_a), (b) Shortwave Radiation and Wind Speed and (c) Temperature Difference Between Water and Air Temperature*



Heat Fluxes of the Harbor Surface

The hourly amounts of the heat loss from the surface for the entire observation interval (Figure 4) point to that the dominant component of the heat loss was net long wave, the flux of latent heat and flux of sensible heat (fluctuated between positive and negative values according to the temperature difference between SST and T_a). During the days, latent heat changed from 2.02 to 383.30 W/m^{-2}, Lw_{net} from 138.30 to 197.90 W/m^2, and sensible heat from -49.23 to 40.00 W/m^2. During some hours of some days, latent heat loss was greater than net long wave radiation (22.73%).

The maximum loss of total heat (Lw_{net} + E + H) during ordinary days was 582.05 W/m^2. The output results of big loss of heat was made by an increase in the latent and sensible heat fluxes created by high winds and a big SST-T_a temperature difference as shown in Figure 2. Table 1 represents the relationship between wind speed, SST-T_a temperature difference and the magnitude of latent heat, sensible heat and the total heat loss from the study area. From this table the maximum total heat loss (Lw_{net} + E + H) related to; high wind speed 8.05 m/s (not associated with highest wind speed), almost low temperature difference 1.24 °C and moderate relative humidity 54%. High total heat loss was 497 W/m^2 associated with highest wind speed 9.38 m/s, nearly low temperature difference 1.34 °C and relatively high relative humidity 70%. The highest temperature difference 7.44 °C, moderate wind speed 2.23 m/s and high relative humidity 88% were produced the highest sensible heat 40.00 W/m^2, moderate latent heat 145.17 W/m^2 and relatively high total heat loss 377.57 W/m^2. Eastern harbor great flux appears related to a low sensible heat, created by a low SST-T_a temperature difference, and a larger latent heat related to high wind speed at the time of comparatively low relative humidity.

Figure 4. *Hourly Values of Heat Losses from the Surface as Latent and Sensible Heat, Net Long Wave and Sum of All of Them*

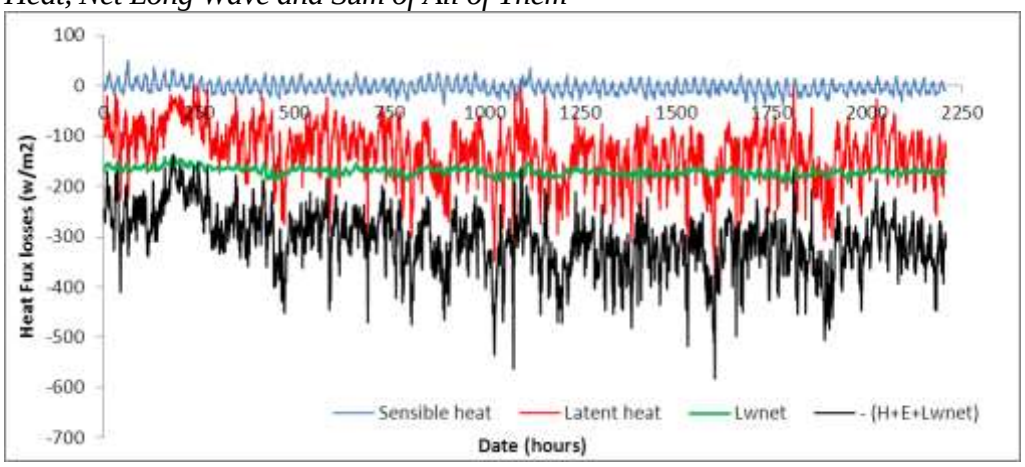


Table 1. *Physical Parameters of Alexandria Eastern Harbor*

Humidity	SST	Ta	SST-Ta	Wind Speed	H	E	Lw_{net}	H+E+Lw_{net}
54	29.01	27.78	1.24	8.05	15.89	383.30	182.86	582.06
70	28.56	27.22	1.34	9.39	19.85	304.97	172.28	497.10
88	29.67	22.22	7.45	2.24	40.01	145.18	192.39	377.58

Daily Variability

Table 2 represents the major characteristics of the fluxes of latent and sensible heat and their input variables determined that the two most paramount components of the flux of latent heat are humidity deficit (q_s-q_z) and wind speed.

Mean daily magnitudes of relative humidity fluctuated between 55.82% (minimum) at 15:00 PM and 79.11% (maximum) at 05:00 AM (Figure 5b) in inverse relationship to maximum and minimum temperatures of air, respectively (Figure 3a).

Vapor pressure saturation (e_s) at air temperature (Figure 5b) followed T_a, with a maximum at 15:00 h, but vapor pressure (e_a) (Figure 5a), was nearly minimum at this time, due to the relative humidity reduction. Vapor pressure saturation (e_{sat}) at water temperature followed SST, with a maximum value at 17:00 h and minimum value at 07:00 h. Although q_s and q_z based on surface atmospheric pressure, their variability is almost equal to that of e_{sat} and e_a because the alteration in atmospheric pressure is only 1.38 hPa (0.14%) during the day.

Table 2. *Heat Fluxes (Hourly Mean) and Their Input Components*

	Max	**Min**	**Δ (%)**	**Time Max**	**Time Min**
ρ_{air} (kg/m^3)	1.17	1.15	1.80	6:00 AM	3:00 PM
10^{-2} L_v (J/kg)	24354	24330	0.09	7:00 AM	4:00 PM
10^3 (C_e = C_h)	1.85	1.13	63.05	6:00 AM	3:00 PM
U (m/s)	5.72	3.09	84.77	4:00 PM	6:00 AM
10^3 (q_s-q_z) (kg/kg)	9.35	7.51	24.43	5:00 PM	8:00 AM
SST - T_a (°C)	2.91	-1.86		6:00 AM	3:00 PM
E (W/m^2)	181.12	103.64	74.76	5:00 PM	8:00 AM
H (W/m^2)	16.5	-12.14		5:00 AM	3:00 PM

Figure 5. *Daily Variability of (a) Vapor Pressure (e_a) at Air Temperature, and Saturation Vapor Pressure (e_{sat}) at SST, (b) Saturation Vapor Pressure at Air Temperature, and Relative Humidity (R_h)*

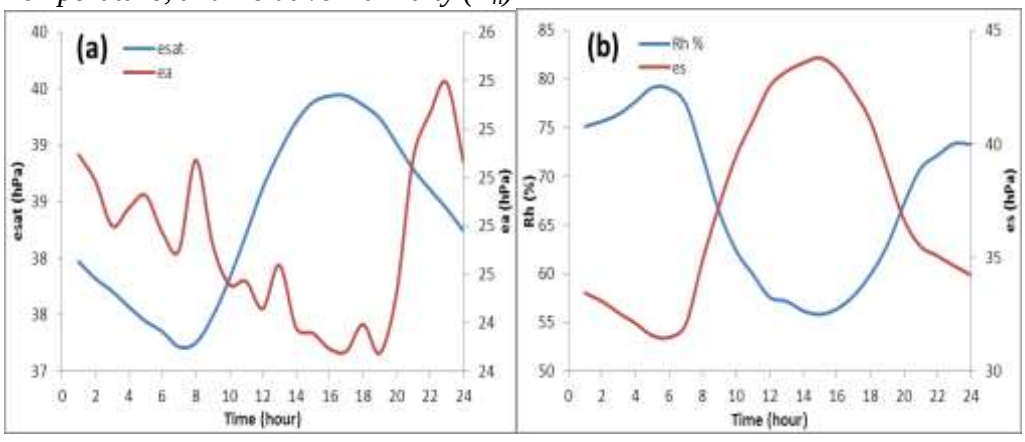


Figure 6c represents the mean daily variability of q_s-q_z. The maximum of humidity deficit occurred at 17:00 h (Table 2) because the minimum of q_z is nearly

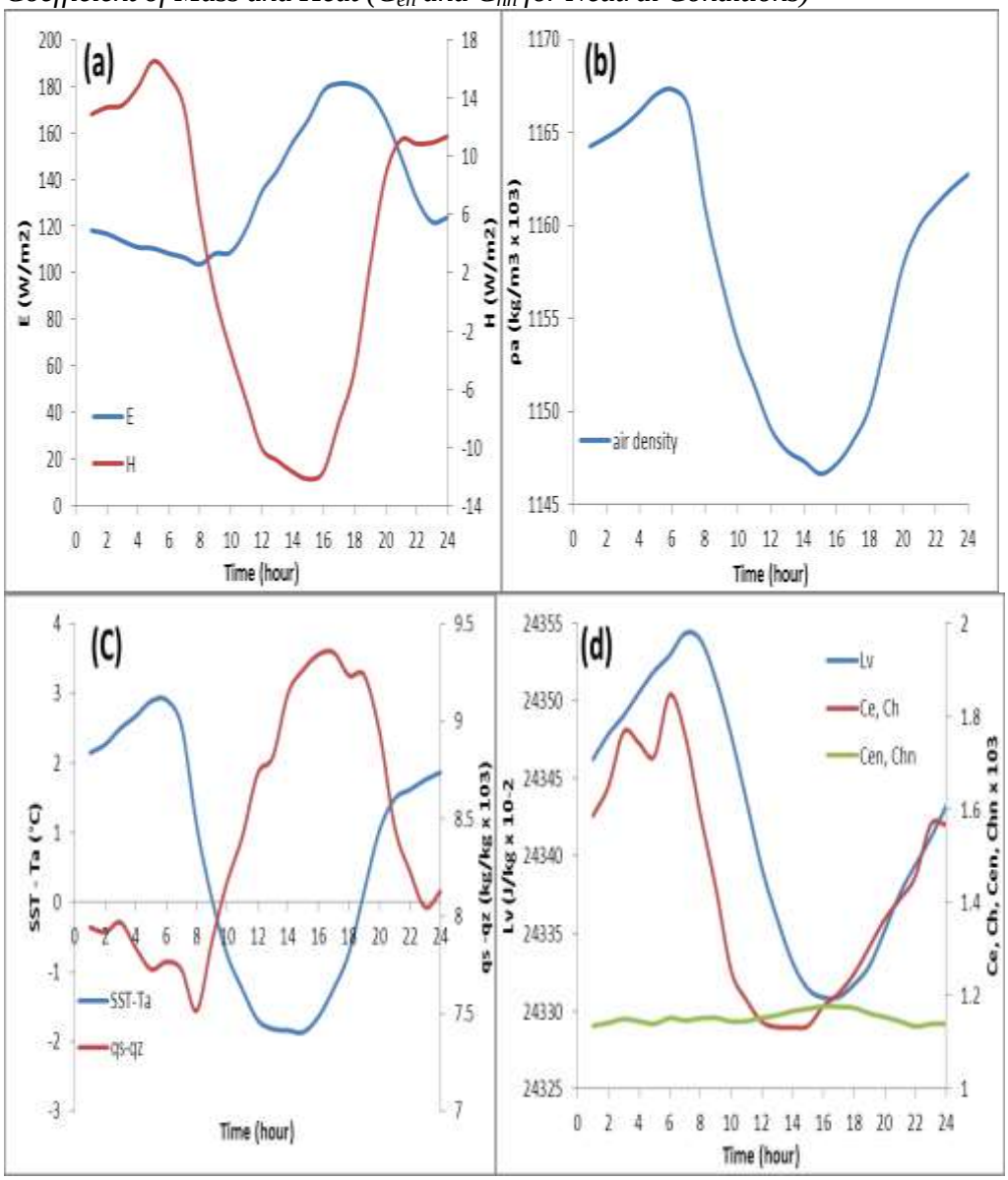
simultaneous with the maximum of q_s at this time during the day. So, the maximum humidity deficit q_s-q_z is mightily predominated by the decrease in relative humidity linked to the air temperature peak.

Maximum value of latent heat (181.12 W/m^2) was observed at 05:00 PM (Figure 6a, Table 2), when surface wind speed reached 5.69 m/s second highest value (Figure 3b). The decreases in latent heat between 01:00 AM and 08:00 AM and between 18:00 h to 23:00 h were quite determined by the decrease of the wind speed at these time intervals. Note that latent heat grew and fall during 24 hours also seems to be related with the q_s-q_z behavior (Figure 6c). The latent heat minimum value (103.64 W/m^2) was observed at 08:00 AM (Table 2), also q_s-q_z was observed in minimum value at 08:00 AM (Table 2). This analysis represents that, while the wind speed controls latent heat and q_s-q_z, portion of the latent heat variability is still dominated by humidity deficit (q_s- q_z).

Variability in latent heat of vaporization and air density (Figure 6b, 6d), which may be affect latent heat, were in phase with changes in sensible heat flux but not in phase with variations in flux of latent heat, their percent changes (Table 2) were very small to share in significantly to the latent heat variability.

The variability of the flux of sensible heat was not in phase with the flux of latent heat (Figure 6a). Note, that at 17:00 h, while maximum latent heat was 181.12 W/m^2, H was (-8.20 W/m^2), a result of a small SST-T_a temperature difference -1.23 °C (Figure 6c) and a high wind speed 5.68 m/s (Figure 3b) at this time of day. Sensible heat reached its maximum of 16.5 W/m^2 at 05:00 AM when SST − T_a was maximum (2.91 °C) and the wind speed was relatively low. In a mean daily sense, sensible heat flux was positive and negative during the day. On hourly basis (Figure 2) during afternoon and midafternoon hours, air temperatures can override SSTs, leading to negative flux of sensible heat (eastern harbor gaining or obtaining sensible heat). Sensible heat is a function of wind speed; winds are usually high during this time of the day. The average wind speed corresponding to these negative sensible heat fluxes was 5.07 m/s, resulting in high sensible heat flux gains in Eastern Harbor (average value of −9.36 W/m^2). Also, take into account that during many hours sensible heat is positive (Eastern Harbor losing sensible heat) during the day. In an average sense, one can consider the values of sensible heat nearly positive (about 66% of the observation period) during the day.

Figure 6. *Daily Variability of Heat Fluxes (Sensible (H) and Latent (E)), (b) Air Density (ρ_a), (c) Temperature Difference Between SST-T_a and q_s-q_z, (d) Transfer Coefficient of Mass and Heat (C_{en} and C_{hn} for Neutral Conditions)*



Fluxes of sensible and latent heat are influenced by variations in the exchange coefficients (C_h and C_e), that increment from their neutral magnitudes when the atmospheric boundary layer is unstable. In generic, cooler air above warmer water is related with unstable atmospheric conditions, nearly prevailing condition in Eastern Harbor. For humid and hot situations such as occur in summer season of the Eastern Harbor, atmosphere of Eastern Harbor can be unstable in that season, even when SST − T_a = 0 (Hussein 2019) due to buoyancy has been induced by water vapor (Liu 1990). The parameter of stability ζ was nearly negative during 85% of the observation period. The estimated coefficients of heat transfer (Figure 6d) were nearly consistently over their neutral magnitudes, except from 12:00h to

16:00h were slightly below their neutral magnitudes. C_e and C_h, which were increase generally from midnight until 06:00 AM, then decrease rapidly until 011:00 AM and again increase from 16:00 h until nearly midnight, an increase associated with the decrease of the wind speed during this period (Figure 3b) accompanied by SST − $T_a \approx 1.31$ °C; a maximum negative $\zeta = -6.65$ was reached at this time. Between 16:00 h and 17:00 h, the atmospheric boundary layer was still unstable but at its minimum negative $\zeta \sim -0.032$ when the SST–T_a is only -1.43 °C and wind speed is near its maximum; C_e and C_h were closest to their neutral conditions at this time of the day (Figure 6d). Even when SST and T_a temperatures difference were close to 0 °C near 09:00 AM (Figure 6c), $\zeta \sim -1.74$, and C_e and C_h were well above C_{en} and C_{hn}, the corresponding coefficients under neutral condition.

For the observation period, the average value of C_{en} was 1.15×10^{-3}. During the unstable conditions watched in Eastern Harbor, the average value of the heat transfer coefficients was 1.43×10^{-3}, a 24.26% increase above their neutral values.

Because the differences of pressure of water vapor (e_{sat}-e_a) depend on T_a, SST, R_h and atmospheric pressure, and influence instability *(*ζ) and evaporation, they are beneficial or helpful for comparing buoyancy of water vapor and instability for various water bodies. For the study area e_{sat}-e_a varied from 3.35 to 27.41 hPa with a mean of 13.62 hPa. The similar (min, max, mean) q_s-q_z magnitudes, were 2.06×10^{-3}, 16.93×10^{-3}, and 8.40×10^{-3} for Eastern Harbor, respectively. Consequently, in generic, the water vapor effects on latent heat and on atmospheric boundary layer instability in Eastern Harbor with about 3.35% and 27.41% greater for least and for extreme humidity deficits, respectively.

By linear regression fitting of latent heat (E) versus q_s-q_z, wind and their multiplication, and sensible heat (H) against SST-T_a, wind, and their multiplication, it is probable to get or gain additional quantitative account of the reliance of E and H fluxes to those variables. In Eastern Harbor, wind clarified 50% of latent heat variance, whilst humidity deficit clarified only 39%, and their multiplication 88% (Table 3). Note, the correlation between U and q_s-q_z in study area is very weak ($r^2 = 0.0014$).

For Eastern Harbor, whilst SST−T_a has a predominant effect on sensible heat, the wind has moderate effect in modifying the sensible heat flux (Table 4). A weak correlation between wind and sensible heat was detected over the observation period ($r^2 = 0.24$). At Eastern Harbor, diurnal variations of sensible heat were robustly bound to the changes in temperature differences (SST-T_a); $r^2 = 0.87$ (Table 4). For Eastern Harbor, the nearly perfect fit of latent heat versus the multiplication U (q_s-q_z); $r^2 = 0.88$ (Table 3) and sensible heat versus U (SST-T_a); $r^2 = 0.93$ (Table 4) represents that latent and sensible heat can be precisely estimated via these linear relations with RMSE of about 19.14%, 3.1% of both latent and sensible heat, respectively.

Table 3. *Correlation Between Latent Heat and Humidity Deficit and Wind Speed*

		(q_s-q_z)	**U**	**U* (q_s-q_z)**
E (W/m^2)	r^2	0.39	0.50	0.88
	RMS	43.04	39.06	19.14

Table 4. *Correlation Between Sensible Heat and the Differences Between (SST-Ta) and Wind Speed*

		U	**(SST - T_a)**	**U* (SST - T_a)**
H (W/m^2)	r^2	0.2	0.87	0.93
	RMS	20.96	4.33	3.1

An additional way of examining the relative impacts of humidity deficit, wind and air–SST differences on fluxes of latent (E) and sensible (H) heat is to assess the dependence of the variations of heat fluxes (*dE/E* and *dH/H*) on the fractional alteration of input variables, moisture difference at near surface *Δq* (*dΔq/Δq*), wind *Uz* (*dUz/Uz*) and air–SST *ΔT* (*dΔT/ΔT*). The resulting in *dΔq/*Δ*q* = 0.21, *dUz/Uz* = 0.62, and in case of *SST>Ta, dΔT/ΔT* = 0.91 and for SST<Ta, *dΔT/ΔT* = 0.79. Thus, at eastern harbor variation in wind speed are more important than the changes of humidity deficit q_s-q_z for the variability of latent heat (E) flux.

For the variability of sensible heat (H) flux at Eastern harbor, the air-SST changes dominate rather than the wind (whether, Ta>SST or Ta<SST), in spite of the fact that wind changes are still important and significant.

For the summer season (observation period) at Eastern Harbor, the Bowen ratio changed from a minimum of -0.11 (sensible heat = -12.14 W/m^2 at 3:00 PM; latent heat = 103.64 W/m^2 at 8:00 AM) to a maximum 0.09 (sensible heat = 16.5 W/m^2 at 5:00AM; latent heat = 181.12 W/m^2 at 5:00 PM). This intrinsic variation in the Bowen ratio from minimum to maximum (0.77-fold) is moderate identified by an increase of sensible heat flux generated by the combined effect of slightly increases of wind speeds and maximum increase of SST–T_a temperature differences during early morning time (5:00 AM), on other hand latent heat flux decreases at early morning.

The changes of sensible heat also point out that at night, and especially near sunrise, the influence of sensible heat on the Eastern Harbor atmospheric instability is quite higher. Note that there is no effect of atmospheric stability on Bowen ratio. Because the exchange coefficients (C_e and C_h) have been assumed to be equal, the modifications of these 2 coefficients created by variations of atmospheric boundary layer instability are equal, and then the ratio of sensible heat and latent heat is independent of the surface atmospheric instability.

Net flux of long wave (Lw_{emi} – Lw_{inc}) hourly mean was positive (Eastern Harbor losing energy) during the day, changing from a minimum of 165.63 W/m^2 at 11:00 AM to a maximum of 173.52 W/m^2 at 06:00 AM (Figure 7a, Table 5). The fluxes of long wave (incident and emitted) were nearly in phase (Figure 7b), with their minimum and maximum at about 06:00-07:00 h and 15:00-16:00 h, respectively.

Due to the SST small period variability (Figure 3a), Lw_{emi} represents only a small value of about 5.97 W/m^2 in contrast Lw_{inc} represents almost high change of about 12.25 W/m^2 (Table 5). The outcome was that the Lw_{net} maximum value was highly specified by the Lw_{inc} minimum value, which happens at 06:00 AM.

Figure 7. *Daily Variability of (a) Net Heat Flux of Long Wave (Lw_{net}), (b) Emitted and Incident Long Wave, Lw_{emit}, Lw_{inc} Respectively, and (c) Air Emissivity ε_a*

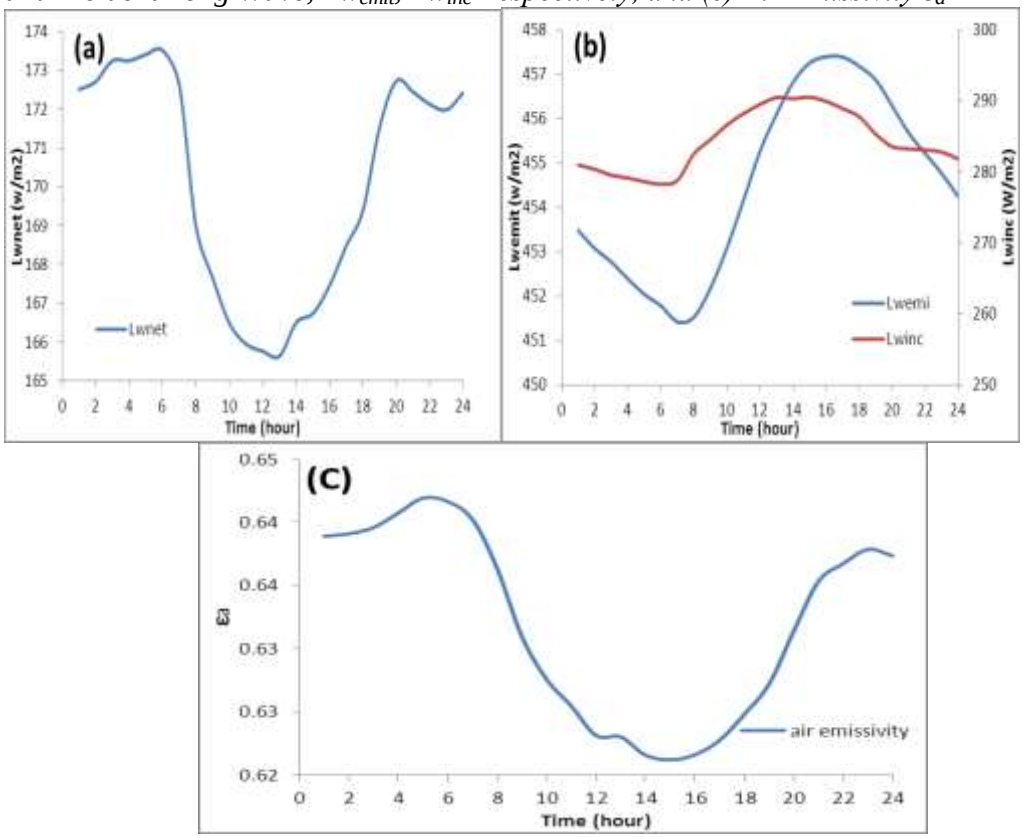


Table 5. *Heat Fluxes of Incident, Emitted and Net Long Wave and Input Variables*

	Max	Min	Δ (%)	Time Max	Time Min
ε_a	0.642	0.621	3.3	15:00	05:00
T_a	30.495	24.813	22.9	15:00	06:00
SST	28.654	27.665	3.5	16:00	07:00
Lw_{inc}	290.511	278.255	4.4	15:00	06:00
Lw_{emi}	457.395	451.418	1.3	16:00	07:00
Lw_{net}	173.523	165.639	4.8	16:00	06:00

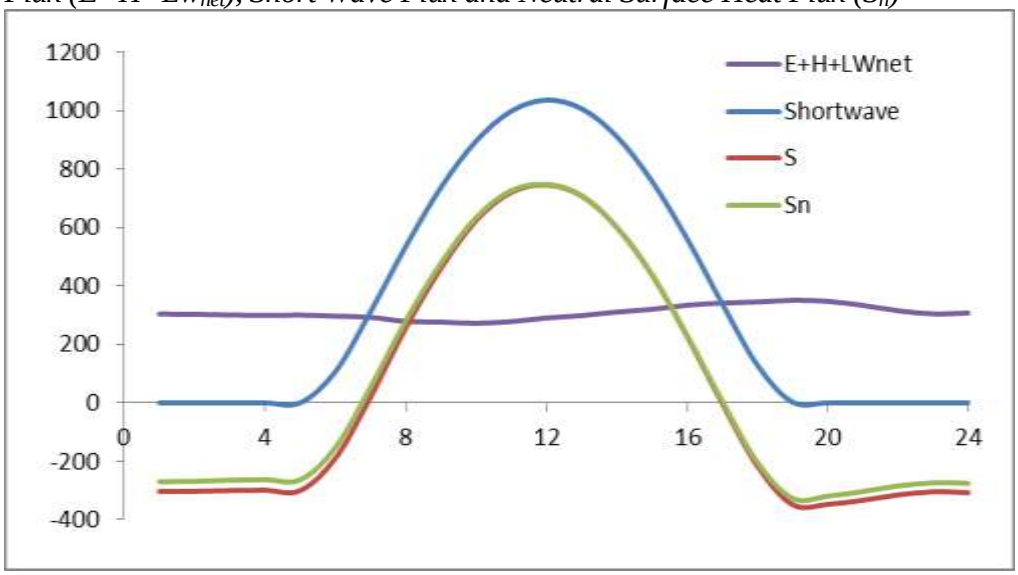
Air emissivity (ε_a) (Figure 7c), which modifies Lw_{inc} (equation 5) depends nonlinearly on vapor pressure (e_a) and depends inversely on air temperature (Figure 5a,& 3a). By comparing the changes of ε_a (Table 5) and the incident flux of long wave, its secondary effect on Lw_{inc} is explicit.

The ratio of Lw_{net} to the fluxes of latent heat varied from 102% (at 17:00 h) to 164% (at 08:00 h), and the maximum net long wave was about 108% greater than the max flux of sensible heat. These figures obviously display the importance of the Lw_{net} in the total heat flux balance of the surface (S).

The daily variability of mean balance of surface heat flux (S) for the observed period (Figure 8) represents that the average heat balance at the surface of Eastern Harbor was positive (warming) for about 10 hours around solar noon. The daily cooling period starts at 17:00 h and continue till early morning at 06:00 h; it is

highly specified by the latent heat (evaporative losses). Before and after this phase, winds were nearly enough to promote the loss of latent heat to 107-181 W/m^2, making the magnitude of heat balance negative.

Figure 8. *Surface Daily Variability of Fluxes of Heat Balance (S), Net Short Wave Flux (E+H+Lw$_{net}$), Short Wave Flux and Neutral Surface Heat Flux (S$_n$)*



At Eastern Harbor, a daily average net heat flux of 38.52 W/m^2 was obtained by estimation of surface heat balance (S) over the day. By using the conditions of neutral stability (S$_n$ in Figure 8), drives to a daily average net heat flux of 59.67 W/m^2, an obvious indication of the important role of the atmospheric instability on the estimated fluxes of heat and net heat balance for Eastern Harbor.

Variations in SST are not only specified by the net heat flux of surface; also they depend on many others parameters (Kim 1976, Imberger 1985, Imberger and Patterson 1990, MacIntyre et al. 2002). If daily mean variability of SST is correlated with S, however in principle, S should be the predominant factor. In comparing the daily variability of SST (Figure 3a) and S (Figure 8), SST started to grow at 08:00 AM, coinciding with the starting of a positive value (phase) of S. The increase of SST stopped at 17:00 h when S turned into zero. From this time until 07:00-08:00 AM, when S value was negative, SST decreased till its minimum magnitude at 07:00-8:00 AM. So, at least qualitatively, one can say that the observed variations of SST were governed by the net heat flux of the surface. The negative mean daily heat balance of surface through the period of the study indicates that energy is losing from Eastern Harbor.

Conclusions

Eastern harbor plays undoubtedly an important role as commercial environment for fishermen in addition to the uses of the eastern port in marine sports.

The work explained in this manuscript was part of attempt and effort to combine and collect data in Eastern harbor and from it obtain a preferable description of each component of heat flux and the net heat flux of surface of AEH in a mean daily time frame. It particularly confirms understanding the relatively significance of each term or parameter of the budget of surface energy and how the value of each is governed by physical variables input during the daily cycle.

The latent heat (evaporative lose) was the predominant emission component of the heat flux (surface) at AEH. Higher latent heat value happens ordinarily at night when speed of wind is second highest value and minimum at morning when speed of wind is also second smallest value. During the observed time period, the mean latent heat was 141.38 W/m^2.

Wind over Eastern harbor was the main factor governing heat losses due to evaporation; the humidity deficit exclusively demonstrated about 39% of the variability of Latent heat (E).

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Sustaining Solutions in Undergraduate STEM Education

By Ellene Tratras Contis[*] *& Batoul Abdallah*[±]

Science, Technology, Engineering and Mathematics (STEM) programs that attract and sustain student interest feature learning that is experiential, investigative, hands-on, personally significant to both students and faculty, connected to other inquiries, and suggestive of practical application to students' lives. Such learning flourishes in a community in which faculty are committed equally to teaching, to maintaining their own intellectual vitality, and to partnering with students in learning, and in which institutional support for such a community exists. The Creative Scientific Inquiry Experience (CSIE) Program at Eastern Michigan University (EMU) is involved in retaining and increasing the number of STEM graduates by including faculty professional development, student connectedness to the sciences and mathematics through academic service-learning, and curricular reform. In this conference paper we report on the success of the CSIE program, including course development, student engagement, student success, especially among underserved students, and sustainability. This work is important because it offers insight into the development, sustainability, and scalability into faculty-driven STEM education reform spanning 15 years.

Keywords: *STEM education, retention strategies, undergraduate STEM, majors/non-majors*

Introduction

STEM education currently faces significant challenges related to retention and achievement, especially among undergraduate students. Approximately 20% and 28% of freshmen in 2-year and 4-year institutions, respectively, declare a major in a STEM field. However, 69% and 48% of those students leave STEM before earning a college degree (Meyers and Jones 1993). Most students who declare a STEM major leave STEM fields, citing poor student performance, unengaging coursework and poor teaching by STEM faculty. Another crisis facing STEM is the workforce shortage, as constant innovation drives demand for highly skilled professionals. At the current rate, an estimated one million more jobs will be necessary to meet that demand over the next decade, indicating that the number of graduates of STEM degrees must increase by 34% (Xue and Larson 2015). It is important to note that there is significant variation and even a surplus among workforce demands related to: discipline, education level, sector (government, academia, private), and geographical location (King et al. 2015, Mailloux and Grimaila 2018).

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To address concerns of STEM attrition and workforce shortages, significant investment was made into post-secondary educational programming with an overall goal to recruit, retain, and increase achievement of students in STEM fields. These reforms include the implementation of high impact practices such as the creation of faculty and student learning communities, course-based and summer undergraduate research, mentoring, academic support, among others. Many of these reforms have worked at recruitment, retention, and increasing student engagement and achievement in STEM fields (Caniglia and Tratras Contis 2013, Estrada et al. 2016, Kendricks et al. 2019, Theobald et al. 2020, Tratras Contis 2014). Specifically, course-based undergraduate research experiences (CURE) are among the strongest best practices for increased student engagement. CUREs can be designed to be scaffolded throughout students' academic careers to include research, career development, and internships (Ashcroft et al. 2020). CURE's are highly effective at building a strong STEM identify, increasing students' confidence in science and in research aptitude, and building self-efficacy, particularly among underserved students (Ashcroft et al. 2020, Syed et al. 2019). Taken together, undergraduate research experiences strengthen career pipelines as students acquire knowledge and skills necessary for STEM careers. Despite the successes of many best practices, including undergraduate research, many challenges remain, including closing the achievement gap, inadequate resources for implementation, institutional and faculty-related barriers, and widespread scaling of successful best practices in STEM education.

Here, we report on the Creative Science Inquiry Experience (CSIE) at Eastern Michigan University (EMU). EMU is a state university of about 20,000 undergraduate and graduate students and located in the southeast corner of Michigan. CSIE is an undergraduate seminar STEM program that connects students with faculty and community projects with an integrated science curriculum. The impacts on STEM students, faculty, curriculum, and community involvement will be reported, as well as, the benchmarks used to measure the success of our students. Specifically, we discuss our successes with faculty professional development and course development, the creation of an inclusive STEM culture, and its subsequent success on student achievement, especially among underserved students. We also discuss our efforts on sustainability and possibilities for scalability into other institutions.

Methodology

Many universities experience several challenges and barriers to STEM learning. EMU experienced many, including the following: siloed STEM departments; lower STEM retention, lower next-in-progression enrollment (students did not continue in their STEM coursework); student interest waned after first term due to amount and difficulty of coursework; no mentoring/advising, and no connections to faculty; lower diverse STEM population, especially among underserved groups.

We are fortunate to have opportunities at EMU that include EMU faculty who are really interested in helping our students get a solid STEM education. We have a focus on undergraduate research and many of our faculty have students who work in the lab, alongside graduate students. Our students present at regional/ national conferences and coauthor manuscripts for publication. Our Faculty Development Center is strong and supportive in providing professional development for out faculty and is run by a biology faculty. Our location in southeast Michigan positions us for connections and partnerships to our local and large STEM industries of which auto manufacturing is key. Our University leaders encourage faculty-driven change. We have a diverse student body – according to US World & News report, EMU is the most diverse university in the Midwest United States.

Therefore, the elements to a solution for us included hands-on (experiential) learning strategies where students and faculty collaborate with community partners to solve local issues. Faculty interdisciplinary teams were formed to develop and implement interdisciplinary seminars. We wanted culturally relevant connections to the community. We wanted to develop a sustainable program to increase community awareness with faculty and students.

Program Description

The CSIE program at Eastern Michigan University (Caniglia and Tratras Contis 2013) has created interventions that support high academic standards through increased student success, supporting student academic career development and experiential learning, provide faculty professional development, and institutionalization of key project components. The CSIE model was developed using Academic Service-Learning (ASL) and experiential learning approaches. ASL is an innovative teaching and learning practice that connects meaningful, community-based projects to course content and instruction with the intent of enhanced student and civic learning. Experiential learning is a complex active learning strategy that immerses students in a particular setting and encourages reflection for conceptual and skill development. The CSIE model represents a powerful combination of both strategies by encouraging interdisciplinarity and collaboration between STEM faculty of different disciplines through course development workshops. Faculty focus on identifying courses for integration, common themes, and community and/or industry partners for learning experiences. CSIE is currently being adopted at the institutional level to be sustained beyond grant project completion. The methods used by CSIE to fulfill and institutionalize project objectives are: experiential learning course development, course regularization, course-tagging for transcript recognition of student experience, completion of a STEM student workspace, developing and cultivating community partnerships, faculty professional development, faculty-student mentoring, career exploration, advising and long-term planning and campus and community outreach through informal student learning events.

Creative Science Inquiry Experience is a STEM program first funded by the US National Science Foundation in 2005, and then by the US Department of

Education in 2013 that specializes in creating learning experiences to attract and retain students in STEM fields.

Our learning experiences come in many forms. We partner faculty with community partners to create 1–2 credit seminar courses that supplement STEM courses. These courses use active learning strategies, namely experiential and project-based learning, to engage students in hands-on, community-based projects. We also develop many student events that enhance STEM courses and help connect students to resources, including undergraduate research opportunities, mentoring, advising, career services, and academic support.

CSIE is demonstrated to have a positive impact on both faculty and students. Students develop a larger interest in research opportunities, and through the relationships they build with our faculty fellows, they have more access to them. Students who take our courses are more likely to enroll or participate in undergraduate research. We offer free STEM textbooks for introductory STEM courses through our Book Loan program. We offer advising and mentoring and can further help students set up appointments with faculty, university advisors and career development centers. Students can learn about their career choices in a STEM field. Community outreach is an integral part of the experiential learning component. Through our course projects, students can develop and offer their solutions to local, community problems. Our courses are 1–2 credit hours and therefore not a large time commitment. CSIE offers a transcript endorsement, or a micro credential, for students to showcase their work. We also offer academic support by way of tutoring.

Figure 1. *Titles of Representative Courses Developed for CSIE*

Current and Previous CSIE Courses
Cyanobacteria in the Huron River
Meals on Wheels: Routes and Costs
Organic and Quantitative Analysis
Physics and Engineering
Coaching Science Olympiad
Statistics for Biological Sciences
Algebra Workshop for STEM
Scientific Presentation
Groundwater Studies
Applications in Elementary Math and Physics
Digitized Motion Studies
Structuring Secure Firewalls
Programming for Calculus
Special Topics: Duets Scholars
Ethics of Genetics
Think On Your Feet!
Introduction to Physics and Engineering
Synthesis and Evaluation of Scientific Literature
Water Quality Investigations
Scientific Learning

STEM-IT! Exploring STEM Careers
Contaminants in Groundwater
Indicator Species in the Huron/Rouge River
Modeling Mechanical Systems
Statistics for Biology and Earth Science
Playpump Hydraulics
Math Workshop
Algebra and Trig Applications and Workshop
Modeling with MATLAB
Organic Analysis
5 Miles to Clean Water
Microbes in Health and Disease
Duets Scholars
Video Analysis
Undiscovered Urban Scientists
Physics and Engineering as a Career
Water Quality Investigations
Water Investigation
Surface Water Analysis
Understanding Life in the Universe

CSIE has impacted students in a meaningful and significant way. To date, over 40 courses (Tratras Contis 2014) have been developed and one-third have been regularized (offered consecutive semesters). Depicted in Figure 1 are a sampling of courses with our community partners and federal support. There is a large degree of course diversity. Many courses are CUREs (course-based undergraduate research experience) that offer exploratory research. Other courses are metacognitive in nature where students are taught how to think, study from a disciplinary sense. All courses are project-based and hands-on.

For example, Cyanobacteria in the Huron River (located near the University Campus) is CSIE's first developed and longest running course. It is an interdisciplinary course developed between Biology and Chemistry faculty, and our community partner, the Huron River Watershed Council. Students are given first-hand exposure to significant environmental issues in the Great Lakes region. They perform exploratory research by sampling water from local rivers and lakes to the test the level of cyanobacteria and other potentially hazardous materials. The data generated by the students are shared with the Huron River Watershed Council and other agencies that monitor and generate reports for lawmakers.

The Cyanobacteria course is an example of engaged and culturally responsive coursework that applies concepts from Biology and Chemistry in a real-world setting by analyzing water samples from our immediate environment. Toxic cyanobacteria present a local, serious problem and our approach allows students to develop a deeper awareness and unique skills to investigate, confront and communicate on these issues.

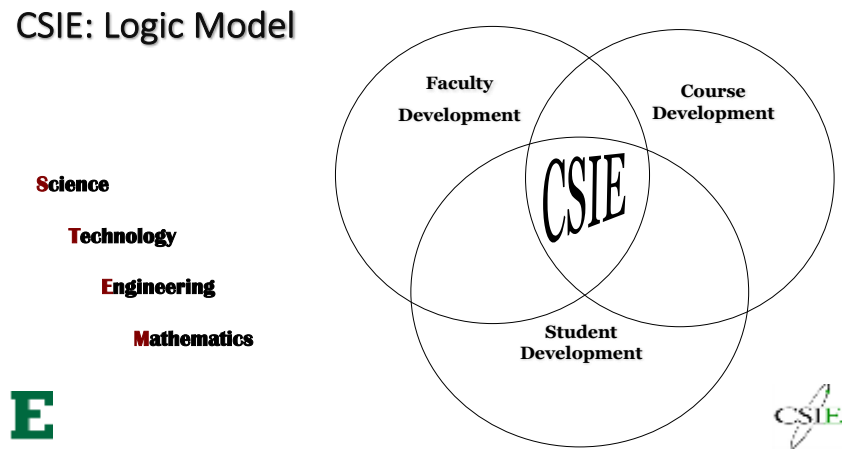
Results

Student data was collected retrospectively from the Office of Institutional Research to determine CSIE impact on student success rates. Student success is measured by graduation time and retention of STEM majors. A retrospective study was completed comparing Biology and Chemistry majors enrolled in CSIE courses, against those not enrolled in CSIE courses over a 13-year period. Demographic data was also collected retrospectively and measured to determine growth/decline of student groups enrolled in CSIE courses, and graduation.

CSIE: Successful STEM Education Intervention

Established in 2005, CSIE specializes in creating learning experiences for students in STEM fields through high impact practices, including Academic Service-Learning (ASL) and experiential learning approaches. ASL is an innovative teaching and learning practice that connects meaningful, community-based projects to course content and instruction with the intent of enhanced student and civic learning. Experiential learning is a complex active learning strategy that immerses students in a setting and encourages reflection for conceptual and skill development.

Figure 2. *CSIE Logic Model*



The CSIE logic model intersects among three key components: faculty development, course development, and student development as seen in Figure 2. The CSIE model represents a powerful combination of both ASL and experiential learning by encouraging interdisciplinarity and collaboration between STEM faculty of different disciplines through course development workshops. Faculty focus on identifying courses for integration, common themes, and community and/or industry partners for learning experiences.

These following statistics demonstrate CSIEs positive impact on the EMU community.

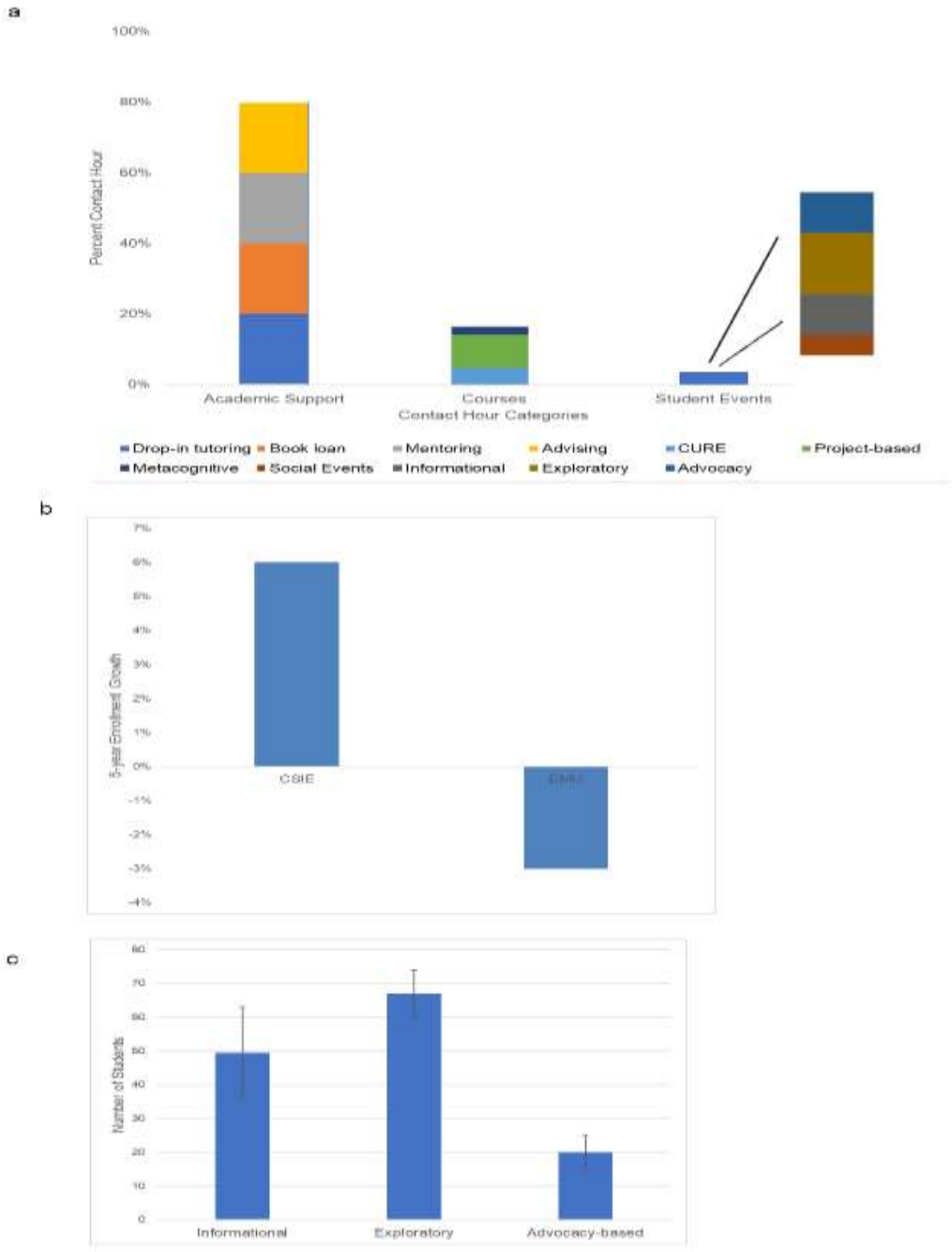
Overall, we have seen an increase in enrollment of 6% over the last five years (beginning of the Department of Education Grant) while the university has seen an overall decrease in course enrollment of 3%. Some of our highest gains have been among underserved groups. We have an 18% increase in female enrollment. We have demonstrated a 28% increase in enrollment among African Americans (Females, 37%; Males, 14%). We continue to maintain an ongoing community connection by making and maintaining community partnerships for course development and student events. We have set ourselves up to become a "one-stop shop" resource for STEM students. Our office and website contain resources and information about STEM departments, centralized in one location for students, faculty, and staff.

Meaningful Student Engagement

In working towards creating an inclusive STEM community fostered meaningful student engagement, mutual respect, and trust, CSIE established a diverse platform of learning experiences that includes courses, student events, and academic support. The multitude of platforms attracted and engaged students with varying degrees of interest in STEM fields. Figure 3a depicts the types and variety of learning experiences offered through the CSIE program that reflect the contact hours students can engage with CSIE faculty and staff. Students can engage in

CSIE activities through course credit hours, CSIE office hours (services include mentoring, advising, tutoring, and other services), and informal student events.

Figure 3. *CSIE Creates Meaningful Student Engagement* (a) *CSIE Meaningfully Engages Students through Academic Support, Seminar Courses and Student Events, Reflected by the Amount of Contact Hours Students can Engage with Faculty* (b) *Increased Enrollment in CSIE Courses Compared to University Enrollment* (c) *Types of Undergraduate Seminar Courses Developed by CSIE Program*



Most courses are exploratory, offering course-based undergraduate research experiences, and project-based learning. Other courses offered are informational, engaging students in career development, and advocacy-based, teaching students, critical agency and metacognitive learning.

Our combined efforts through formal and informal formats represent our ongoing relations with the campus and external communities. Our data indicate that students continue to participate in all activities, especially 1–2 credit hour seminar courses (Figure 3b) as our enrollment has steadily increased even as enrollment at Eastern Michigan University has declined. A variety of high impact practices (HIP) are used to engage students in CSIE courses, including course-based undergraduate research experiences (CUREs), project-based learning, metacognition, career development, and culturally relevant learning (Figure 3c). Altogether, these data indicate that CSIE creates an inclusive STEM community that continues to attract students through culturally relevant and engaging course work, informal and academic support.

This large increase is due to incorporating research experiences in introductory stem courses, as well as incorporating active learning strategies in the curriculum.

Course-based undergraduate research experiences increase participation of first generation and underrepresented students in STEM.

Figure 4. *Samples of Posters and Fliers of Student Engagement Activities*

Figure 4 shows examples of posters and fliers that promote and advertise some of the outreach events sponsored by CSIE. They include webinars (Opioids), Class to Career workshops, chemistry tutoring sessions and math summer bridge programs (STEM-a-Thon), solvathon (SolvEMU), professional presentations at regional and national STEM meetings, and partnerships with our local agencies.

CSIE Increased Impact on Student Success

Enriched learning experiences have positive impacts on student success rates, including academic years before graduation, STEM retention and increased participation among underserved students. CSIE courses have positively impacted student graduation rates. As shown in Table 1, 53% of CSIE students graduate within four years, compared to 45% of EMU students. Among STEM majors, more students who majored in a STEM field and enrolled in a CSIE course graduated than non-CSIE STEM majors, 54% to 51%, respectively. Finally, 78% of students enrolled in a CSIE course during their first two years graduated from EMU within 4 years, as compared to 45% of EMU students not enrolled in a CSIE course.

CSIE has also positively impacted STEM retainment. Student data indicate that more students enrolled in a CSIE courses graduated with a STEM major, as compared with non-CSIE STEM majors, 63% to 58% respectively (Table 1). An analysis on next in progression enrollment, indicating continuation of STEM coursework supports this finding (Table 1). A larger number of students enrolled in introductory Biology and Chemistry concurrently in a CSIE course continued with subsequent coursework when compared to non-CSIE university students: introductory Biology (CSIE 66%; non-CSIE 49%) and introductory Chemistry courses (CSIE 71%; non-CSIE 21%). Overall, the combination of faster graduation time and increased STEM retention of STEM majors and STEM coursework demonstrate the efficacy of the CSIE platform to increase student success.

Table 1. *Student Success Statistics, Demonstrated by Time to Graduation, Retention of STEM Majors, and Retention in STEM Courses*

CSIE Increases Student Success Rate	**CSIE**	**EMU**
Graduation within 4 years	53%	45%
Graduation within 4 Years among STEM Majors	54%	51%
STEM Graduates	63%	58%
Next in Progression Enrollment		
Biology Enrollment	66%	49%
Chemistry Enrollment	71%	21%

Students who take our courses graduate faster than non-CSIE students. As such, 78% of students enrolled in a CSIE course during their first two years graduate within 4 years, as compared to 45% of non-CSIE students who graduate in 4 years. The CSIE model is successful at recruiting and retaining STEM majors. A survey of CSIE student majors has shown that we retained 61% of STEM majors and recruited 21% of non-STEM majors.

CSIE is also successful in course retainment through a measure called "next in progression courses". For example, "Biology 1" is followed by "Biology 2", with "Biology 2" being the next in progression course. Students enrolled in CSIE courses are more likely to enroll in next in progression courses. In Biology, 66% of CSIE students compared to 49% non-CSIE enrolled in the next course progression; in Chemistry, 71% of students enrolled in a CSIE course enrolled in

the next course progression, as compared with 21% of non-CSIE chemistry students.

Many CSIE students continue the research track. Finally, a post-graduate survey found that 62% of CSIE students work in a STEM profession. 47% went on to complete a post-graduate degree, compared to 36% of EMU students.

Broadening Participation

Broadening participation in STEM by promoting diversity and inclusion is a central goal of national STEM education reform. The combination of high impact practice through courses, student events, and academic and social support enabled the CSIE model to broaden participation among underserved student groups. Table 2 demonstrates enrollment demographics over five-year time period, indicating 18% growth in female enrollment. Additionally, enrollment grew among African Americans by 28%, specifically 37% growth among African American females and 14% increase among African American males.

Table 2. *STEM Majors among Underserved Students - CSIE STEM Graduates Greater Numbers of Underserved Students*

		2007/08		**2008/09**		**2009/10**		**2010/11**		**2011/12**		**2012/13**	
		CSIE	EMU	CSIE	EMU	CSIE	EMU	CSIE	EMU	CSIE	EMU	CSIE	EMU
Male	Underserved White	0%	17%	22%	13%	10%	11%	20%	15%	13%	6%	25%	16%
Male	Underserved White	100%	83%	56%	80%	90%	77%	67%	78%	81%	85%	67%	74%
Female	Underserved White	0%	20%	20%	33%	22%	29%	31%	9%	13%	20%	38%	20%
Female	Underserved White	100%	60%	70%	44%	44%	62%	62%	82%	73%	73%	62%	80%
		2013/14		2014/15		2015/16		2016/17		2017/18		2018/19	
		CSIE	EMU	CSIE	EMU	CSIE	EMU	CSIE	EMU	CSIE	EMU	CSIE	EMU
Male	Underserved White	11%	11%	20%	25%	29%	0%	27%	10%	7%	11%	24%	0%
Male	Underserved White	79%	75%	60%	70%	64%	100%	64%	80%	86%	78%	65%	100%
Female	Underserved White	11%	35%	16%	29%	29%	29%	50%	40%	29%	42%	28%	0%
Female	Underserved White	78%	57%	72%	57%	71%	71%	50%	40%	53%	42%	67%	100%

These increases in enrollments translated into an increased number of graduates. Over a 12-year time period, CSIE female graduates outnumbered non-CSIE university graduates, 55% to 48%, respectively. Furthermore, when gender, race, and major were considered, the CSIE program graduated more underserved students in STEM fields. Specifically, CSIE STEM graduates consistently numbered significantly greater numbers of underserved students, both male and female (Table 2).

CSIE Sustainability

CSIE is currently being adopted at the institutional level to be sustained beyond grant project completion. To sustain CSIE's presence on campus, many

initiatives have been completed. First, it is necessary to secure support from each of the STEM departments. Due to the faculty-driven nature of the CSIE program, continued support and commitment from our faculty members and departments is crucial to continue course development. Second, commitments from faculty development centers for the continuation of course development is crucial in maintaining exciting and culturally relevant coursework. Third, it is necessary to continue to develop and cultivate external partnerships with non-governmental agencies (NGOs), government, and industry. Fourth, recognition of student work through transcript recognition allows students to showcase their experiences to employers. The connection to employers affirms our significance on campus and within the greater community. Finally, the CSIE program has established a STEM Center and active learning sites. The CSIE office functions as a STEM center that connects students to resources on campus, while active learning classrooms are available for CSIE faculty fellows to teach CSIE courses throughout the year.

Conclusions

Enacting deep and meaningful institutional-level and faculty-level change for a more cohesive and inclusive STEM learning culture is difficult. It is even more difficult to scale successful programs to secondary sites, as success stories are limited to primary sites and expansion efforts often fail. The reasons behind the failure to scale are many: inadequate resources; unaligned goals among administration and faculty; insufficient institutional support; lack of ownership in change initiatives; and improper communication channels. Few undergraduate STEM programs have been successful at scaling to secondary sites, consisting of interventions that are: low-cost, not complex, adaptable, and aligned goals among stakeholders.

EMU believes that the CSIE program is an established part of the STEM culture at EMU. It will continue to grow as a critical mass of STEM faculty (about 50%) continue to include community-based research experiences in introductory STEM courses, as well as incorporating active learning strategies in the curriculum; and to work collaboratively between departments and with our community partners. We also know that course-based undergraduate research experiences increase participation of first generation and underrepresented students in STEM.

It is hoped that the program expands to all STEM departments and that this model is replicated at other similar institutions.

Acknowledgments

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We would like to thank EMU for providing office space for the program and the US Department of Education for funding an active-learning project-based lab in the newly renovated Strong Science Hall on EMU's campus. In addition, our heartfelt thanks go to all the students, CSIE Faculty Fellows, our STEM Adviser, and our community partners who continue to collaboratively work to provide our students with innovative, experiential learning opportunities in STEM.

We also want to thank our many staff members, undergraduate, and graduate students for their many hours of creative input into making the program successful. Specifically, our CSIE managers over the years, Anne Seaman, Jace Lisi, Sandra Becker and Batoul Abdallah, who have overseen the day to day operations of CSIE and who have built the program successfully. In addition, we thank our many undergraduate and graduate students who have worked with such enthusiasm and competence over the years, including those in the past few years, Omid Hajihassani, Swetha Sadineni, Sai Priya Marrapu, Leon Bryce and Mariah Brito. With these dedicated students, who not only worked in the program, but also advised, tutored and mentored our STEM students, we have been able to build a robust and energized CSIE.

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The Effect of Various Learning Approaches on Mathematical Learning Outcomes based on the Multiple Intelligences of Students

By Yerizon Yerizon[*] & Atus Amadi Putra[±]

The aim of this paper is to describe the research results on multiple intelligences in mathematics learning, using a descriptive approach. It also ascertains the influence of various learning models on mathematics learning outcomes based on students' multiple intelligences. Student Teams-Achievement Divisions (STAD) and Team Games Tournament (TGT) learning models improved learning outcomes for students possessing logical-mathematical, kinesthetic, and interpersonal intelligences. Furthermore, Group Investigation (GI) and Numbered Head Together (NHT) learning models improved student learning outcomes with logical-mathematical intelligence. Two Stay Two Stray (TSTS) learning model with peer tutors improved student learning outcomes with linguistic, logical-mathematical, and interpersonal intelligences. Team Assisted Individualization (TAI) and Jigsaw learning improved student learning outcomes with linguistic intelligence. Also, TSTS and NHT learning models improved student learning outcomes with logical-mathematical, and interpersonal intelligences.

Keywords: *compound intelligence, learning model, mathematics*

Introduction

There are many students whom experience difficulty while learning mathematics, which makes it difficult to master mathematical concepts. Students experiencing difficulties may lack the initiative to try again and do not ask for help from a teacher. They feel afraid or embarrassed to ask when they do not understand a problem, therefore their learning outcomes are low due to their difficulty (Fadila et al. 2014); for example, calculating the volume and surface area of spaces, solving problems related to circular elements, and the relationship between two circles (Pradana et al. 2014, Sholikhah et al. 2014).

This may be due to the fact that mathematics learning in schools is still teacher-centered and does not pay attention to the multiple intelligences of students (Pradana et al. 2014, Sholikhah et al. 2014, Widyawati et al. 2014, Abidin 2017, Taufik and Adiastuty 2017, Suwanto 2019, Susilo et al. 2018, Laksmiwati and Retnowati 2019). Students have been proven to possess different intelligences. The ones with high visual-spatial intelligence tend to think visually, while the ones possessing verbal intelligence like to read, are good at telling stories, and writing stories or poetry. Students with interpersonal intelligence have good interactions

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with others, are good at establishing social relationships, and are able to know and apply various methods of interacting (Setiawan and Nisa 2018).

Therefore, during learning, the teacher has to pay attention to the intelligence diversity in their students. The learning of mathematics requires conformity with the theory of multiple intelligences (Amstrong 2009, Susilo et al. 2018). To enhance multiple intelligences in learning, many things can be done, such as choosing models, strategies, approaches, and learning media.

Literature Review

The multiple intelligence theory was initiated by Howard Gardner from Harvard University, United States. Howard Gardner is a humanistic psychologist professor of education at the Graduate School of Education. In 1983, Gardner wrote a book titled "Frames of Mind: The Theory of Multiple Intelligences" which was published in 1993.

Gardner (1995) defined intelligence as the ability to solve problems and produce results in a variety of settings and real-life situations (Amir 2013, Taufik and Adiastuty 2017). Additionally, Gardner explained intelligence as (1) the ability to solve problems that occur in human life; (2) problem-solving skills which enable a person achieve the goals of a certain objective or situation; (3) the ability to determine the right direction or method towards a target (Riyanto 2010). There are several kinds of intelligence expressed by Gardner (Hamdi 2011, Amir 2013, Sholikhah et al. 2014, Indriani and Hariastuti 2017, Sunendar 2017, Taufik and Adiastuty 2017, Aini et al. 2018, Setiawan and Nisa 2018, Fathani 2019, Kurniawati and Kurniasari 2019, Laksmiwati and Retnowati 2019, Palayukan and Ledon 2019, Suwanto 2019, Nugroho and Husni 2020) namely:

Verbal Intelligence (Linguistic Intelligence)

This is the ability to use and process words effectively, both orally and in writing. The characteristics of children with prominent linguistic intelligence include writing stories or poetry, reading, telling stories, enjoy learning foreign languages, good vocabulary and spelling, writing letters or e-mail, talking about ideas with friends, a strong ability to remember names or facts, enjoys word games (juggling words, hidden words, scrabble or crossword puzzles, puns or rhymes) and enjoys reading about eye-catching ideas

Logical-Mathematical Intelligence

This is an ability to solve problems involving numbers and logic effectively. Students with high logical-mathematical intelligence show a great interest in exploration. This intelligence has characteristics, specifically a sensitivity to logical relationship patterns, statements and propositions, logical functions and other abstractions (Khiyarusoleh 2018). A person with high logical mathematical intelligence is usually interested in numbers, science, easily performs math

mentally, enjoys solving mysteries, likes to count, make predictions, guess numbers (for instance, the number of coins in a container), easily memorizes numbers and scores, enjoys strategy games such as chess, pays attention to actions and consequences (known as cause-and-effect), spends time doing brain teasers or logic puzzles, likes to check out how computers work and organize information into tables or graphs, as well as how they can use a computer more productively, instead of just playing games.

Visual-Spatial Intelligence

This is the ability to properly capture the visual-space world, such as that of hunters, architects, navigators, and decorators. Students with high visual-spatial intelligence tend to think visually. This intelligence includes sensitivity to colors, lines, shapes, spaces and the relationships between these elements. A spatially intelligent individual usually remembers faces rather than names, likes to draw ideas or make sketches to solve problems, thinks in pictures and easily sees objects mentally. Furthermore, they love to build or construct, enjoys reading, drawing maps, looking at photos/pictures and talk about them, like to see the patterns of the world, doodle, draw in great detail and realistically, remember things learned in form of pictures, observing people performing several activities, solving visual/picture puzzles and optical illusions and builds models or anything in 3-dimensions. Students with visual intelligence are usually rich in imagination, which enables their creativity.

Bodily-Kinesthetic Intelligence

This is the ability to use the body or gestures to express ideas and feelings, similar to that of actors, athletes, dancers, sculptors, and surgeons. Students with above average bodily-kinesthetic intelligence, enjoy moving and touching. They have control, balance, dexterity, and grace in movement, and like to explore the world with their muscles.

Musical Intelligence

This is the ability to develop, express, and enjoy musical notes and sound forms. Students with prominent musical intelligence easily recognize and remember tones. They can also transform words into songs, and create various musical plays. Additionally, they are good at singing the beat of a song properly, musical vocabulary, and sensitivity to rhythm, melody or sound color in a musical composition.

Interpersonal Intelligence

This is the ability to understand and be sensitive to other people's feelings, intentions, motivations, dispositions, temperaments. Students with prominent interpersonal intelligence have good interactions with other people, easily establish

social relationships, and are able to know and utilize various methods of interacting. They are also able to perceive the feelings, thoughts, behavior and expectations of others, and easily cooperate.

Intrapersonal Intelligence

This is related to self-knowledge and the inherent ability to adapt. Students with prominent intra-personal intelligence have a sense of feeling in ongoing situations, understand themselves, and are able to control themselves during conflict. They also know what can be done and what cannot be done in a social environment. Furthermore, they know the right person to approach when they have to.

Naturalist Intelligence

This is the ability to understand flora and fauna well. Students with prominent naturalist intelligence have a great interest in the environment, including animals, at a very early age. They enjoy objects and stories related to natural phenomena, for example the occurrence of clouds and rain, origin of animals, plant growth, and the solar system.

Existence Intelligence

This involves an individual's sensitivity and the ability to answer the deepest problems of human life and existence. Students with such intelligence are curious about human existence, the meaning of life, why humans experience death, and the realities they face. This intelligence was developed by Gardner in 1999.

The benefits of applying multiple intelligence in the learning process of mathematics include (Hamdi 2011, Amir 2013, Pradana et al. 2014, Rofiah 2016, Susilo et al. 2018):

1) Creates student motivation to learning mathematics.
2) Provides various study methods for students according to their interests, and talents.
3) Improves their abilities in their preferred fields.
4) Provides a positive influence in a pleasant learning atmosphere without limiting students.
5) Ability to facilitate students with various types of intelligence (Armstrong 2009).
6) Reduces the tendency of teachers to teach only in accordance with their most prominent types of intelligence.
7) Improve mathematics learning outcomes.

The dimensions of multiple intelligences contained in the 2013 curriculum can be seen in three ways. Firstly, the development of four core competencies (KI), namely spiritual attitudes, social attitudes, knowledge and skills. Secondly,

the application of a scientific approach which includes: observing, questioning, experimenting, associating, and communicating. Thirdly, the assessment system carried out is in form of authentic assessment (Machali 2014).

Methodology

This study was carried out to determine various results on multiple intelligences in mathematics learning. The intensive and rigorous literature review was done to analyze the effect of multiple intelligences in mathematics learning. There were two methods that were used to search the relevant and appropriate literature of the research.

At the first phase, several related electronic databases were explored to investigate for the relevant articles, such as: EBSCO host; Elsevier; Science Direct; Emerald; JSTOR; ProQuest; Sage Publications; SciVerse; Scopus; Springer Link; Taylor and Francis Online; and Wiley Online. The main keywords used were: compound intelligence; learning model; mathematics and learning; twenty-first century teaching and learning; the effective teaching and learning in general, and specifically in mathematics subject at primary to higher institution level. Furthermore, each single journal was examined individually to find more pertinent papers, for example, International Electronic Journal of Mathematics Education; Mathematics Education; Eurasia Journal of Mathematics; Science & Technology Education; Procedia-Social and Behavioral Sciences; Asian Social Science, etc.

At the second phase, the relevant articles were identified based on the pull out bibliography of the crucial articles of the above literature review using the snowballing method. The literature exploration was done from 2019 to 2020 and restricted to only teaching and learning studies available between 2009 and 2019. This leads to the limitation of this study. If it is found that an article fulfilled these two elements: (a) it focused predominantly on multiple intelligences in mathematics learning and learning of mathematics in general and specifically in mathematics subject at all level, (b) the investigation was carried out in the venue of primary to higher institutions and among mathematics educators, then this article will be included in this study. Peer-reviewed articles that were published in academic journals were also included. Furthermore, conference proceedings and theses were also included in this review. Duplication, indistinguishable and identical publications that were deemed irrelevant were removed from the review. Articles were selected for relevance, essentially based on the title, abstracts, and keywords.

Results and Discussion

The research results on students' multiple intelligences in mathematics learning have been conducted by several researchers (Hamdi 2011, Amir 2013, Fadila et al. 2014, Machali 2014, Pradana et al. 2014, Rohman 2014, Safitri et al. 2014, Sholikhah et al. 2014, Widyawati et al. 2014, Miftachudin et al. 2015,

Indriani and Hariastuti 2017, Sunendar 2017, Taufik and Adiastuty 2017, Aini et al. 2018, Susilo et al. 2018, Fathani 2019, Kurniawati and Kurniasari 2019, Laksmiwati and Retnowati 2019, Palayukan and Ledon 2019, Suwanto 2019, Nugroho and Husni 2020).

Hamdi (2011) examined the advantages of learning mathematics through CTL, involving multiple intelligences in building student character. There are seven main components of effective learning involved in CTL: constructivism; questioning; inquiry; learning community; modeling; reflection; and authentic assessment. An example of character that was built is honesty. This was observed in the process of proving the formula, which has to undergo a process of honesty and openness. That is, all related aspects will be disclosed openly and thoroughly, including the consequences of such proof. The results showed that multiple intelligence-based CTL was highly suitable for building student character. This was because in the learning process the teacher incorporated the real world into the classroom and encouraged students to make connections between the knowledge they have and its application in everyday life.

In its application, teachers must have more options for choosing the curriculum. This approach must be adapted to the behavior and abilities of the students. Teachers need to choose strategies that can be used effectively to improve creative thinking, critical thinking and parenting skills. Not all terms can be used in a study. Teachers should try to find information that is relevant to the student's life environment.

Amir (2013) conducted an experiment to determine the effects of multiple intelligence-based mathematics learning. The results showed that through paying attention to the multiple intelligences of students, teachers aroused their motivation to learn. This was attainable, because students learned according to their interests, and talents. Therefore, this method improved students' abilities in their preferred fields, as it provided a positive influence in a pleasant learning atmosphere, without limiting students.

Every student is special; they are very different. The Work Experience Index shows that everyone has nine skills. In the classroom, the teacher has to choose from several faces to get the face. It is very difficult to adapt everything in class. The instructor should pack all materials that are relevant to the environment and that are appropriate for the students.

Fadila et al. (2014) conducted a research in class VII SMP to ascertain the effect of the Student Team Outcome Division (STAD) and Team Games Tournament (TGT) cooperative learning models with a contextual approach to learning achievement. It also aimed to determine the effective aspects of multiple intelligence on student mathematics learning. The results showed that: 1) The outcome of students' mathematics learning using the TGT learning model in a contextual approach was better than the STAD learning model; 2) The outcome of students whose learning involved the TGT model with a contextual approach was as good as the STAD model; 3) Student learning outcomes with logical-mathematical intelligence were as good as kinesthetic and interpersonal intelligence. In addition, the learning outcomes with mathematical logical intelligence were better than visual, kinesthetic and interpersonal intelligence.

The TGT model is better at helping students learn math than the STAD model. In the TGT model, students are motivated to learn about sports. Students enjoy playing with games, however the teacher must be able to manage the activities of this game because it has been demonstrated that many students get distracted by football and forget to study. Students with visual intelligence like this type of learning.

Machali (2014) conducted an experiment to determine the relevance of changes and curriculum development in 2013 to multiple intelligences. The results showed that the 2013 curriculum made room for the development of multiple intelligence dimensions which can be seen in three ways. Firstly, in competency development, which consists of four core competencies (KI), namely spiritual and social attitudes, knowledge, and skills. In the multiple intelligence category, there are dimensions of existential; interpersonal; intrapersonal; linguistic; logical-mathematical; musical; visual/spatial; bodily-kinesthetic; and naturalist/ environmental intelligences. Secondly, the scientific approach is applied, which includes observing, questioning, experimenting, reasoning, associating, and communicating which is very relevant to the development of learning using multiple intelligences. Thirdly, an authentic assessment method is applied, which is also highly relevant.

The 2013 curriculum is designed to fit students' potential through research. Based on step-by-step research, almost all of the students' intellectual potential is affected. However, there are still teachers who have not done their job, due to various challenges such as the support of facilities and the attitude of the teachers themselves.

Pradana et al. (2014) conducted research in class VIII SMP to determine the effect of the NHT-type cooperative learning model using the CTL approach on the subject matter of flat-sided shapes involving students' multiple intelligences. Students possessing the verbal, logical-mathematical, interpersonal, and spatial types of intelligence had the same achievement. This is because during their learning process, they were able to take advantage of their verbal intelligence in understanding each sentence in the given problem. The ones with logical-mathematical intelligence had the advantage in performing calculations in questions. Furthermore, students with interpersonal intelligence were also able to work together, ask questions and discuss with other students. This enabled them to obtain adequate information in order to solve the given problem. In addition, students with spatial intelligence were able to imagine shapes and make pictures that helped to solve problems.

The results of the research include (1) the learning outcome for students that used the NHT-CTL learning model was better than the NHT and direct learning models, while the NHT model was as good as the direct learning model, (2) students possessing verbal, logical-mathematical, interpersonal, and spatial types of intelligence had the same achievement, (3) in each of the multiple intelligences, the learning outcome for students that used the NHT-CTL learning model was better than the NHT and direct learning models, while the NHT model was as good as the direct learning model,(4) in each learning model, the mathematics

learning outcome for students with verbal, logical-mathematical, interpersonal, and spatial intelligence was equally good.

To improve student math, NHT-CTL curriculum should be determined by students' patience in problem solving. In learning with a NHT curriculum, students need to be more responsible and math-minded and expect to do homework. In math, teachers need to use the NHT-CTL curriculum to become more proficient. The teacher should pay attention to, and understand the characteristics of the students; for example, the various skills that students can learn, such as the language, the study of mathematics, math, and differences.

Safitri et al. (2014) conducted research in class VII SMP to determine the effect of using peer tutoring and independent cooperative learning models with e-learning on the subject of algebra involving multiple intelligences. The results are: (1) In groups where students learned using the peer tutoring cooperative learning model, they had better mathematics learning outcomes than students whom used the self-learning model with e-learning and direct learning. In the group where students used the independent learning model alongside e-learning, they had better mathematics learning outcomes than the group taught using the direct learning model. (2) The learning outcome of students having interpersonal intelligence was better than that of students with intrapersonal and linguistic intelligence. Furthermore, the ones with verbal-linguistic intelligence had better mathematics outcome than students with intrapersonal intelligence.

(3) In peer tutoring cooperative learning, the mathematics learning outcome in students with interpersonal intelligence was better than the ones with intrapersonal. Meanwhile, students with intrapersonal and interpersonal intelligence had the same mathematics learning outcome with the ones having verbal intelligence. In independent e-learning, there was no significant difference between the mathematics learning outcome of students having both interpersonal and verbal types. In direct learning, students having intrapersonal and interpersonal types had the same mathematics learning outcome. Furthermore, the interpersonally intelligent students had the same mathematics learning outcome as the ones having verbal, while students having verbal had a better learning outcome than the ones with intrapersonal intelligence.

For the time being during COVID-19, we had to develop e-learning, and there are many times when this course is completed online. Learning partnerships need to be reduced because we need to control the distance to prevent the spread of the virus. If you want to get involved, you also have to go online.

Sholikhah et al. (2014) conducted an experiment in class VIII SMP to ascertain the effect of Group Investigation (GI) and Numbered Heads Together (NHT) cooperative learning models on material tangents to circles involving students' multiple intelligences. The results showed that: (1) The mathematics learning outcome for students whom used the NHT learning model was better than GI and direct learning, while that of students whom used the GI learning model was better than the direct model (Santoso 2010). (2) The mathematics learning outcome for students having logical-mathematical intelligence was better than in individuals with interpersonal and linguistic, while that of students with interpersonal intelligence was the same as verbal intelligence. (3) In the NHT

learning model, the mathematics learning outcome for students having logical-mathematical, interpersonal, and linguistic intelligence were the same.

As a result of this course, the teacher should be able to focus on the diversity of the various skills that are common among the students, including math, social studies, social skills, and intelligence. Many skills affect student achievement. For classes conducted by students with critical thinking, math and / or individual skills, the NHT and GI curriculum can be used as an alternative to learning decisions. For classes where students are proficient in speaking, the NHT learning model can be used as an alternative to new academic activities.

Widyawati et al. (2014) conducted research in class VII SMP using rectangular flat shapes to determine the effect of the Two Stay Two Stray (TSTS) and Numbered Heads Together (NHT) learning models involving multiple intelligences of students. The conclusions obtained are: (1) the TSTS cooperative learning model produced better mathematics learning outcomes than the NHT and direct learning model, while the NHT cooperative learning model produced better outcomes than the direct; (2) The mathematics learning outcome of students having logical-mathematical intelligence was better than the ones with interpersonal and verbal. Furthermore, the learning outcome of students having interpersonal was better than verbal; (3) For students having logical-mathematical intelligence, the TSTS cooperative learning model produced better learning outcomes than the NHT, while the TSTS and NHT cooperative learning models produced the same learning outcome as the direct learning model. For students having interpersonal intelligence, the TSTS-type cooperative learning model produced the same learning outcome as the NHT and the direct, while the NHT-type cooperative learning model produced better mathematics learning outcomes than the direct model. For students having linguistic intelligence, the cooperative learning model TSTS, NHT, and direct learning models produced the same mathematics learning achievement; (4) In the TSTS cooperative learning model, the learning outcome of students having interpersonal intelligence was the same as logical-mathematical, and verbal intelligence. Furthermore, the learning outcome of students having logical-mathematical intelligence was better than the ones with verbal intelligence. In the NHT type of cooperative learning model, the learning outcome of students having logical-mathematical, interpersonal and verbal intelligence was the same. In the direct learning model, the learning outcome of students having logical-mathematical intelligence was better than interpersonal and linguistic intelligence. In addition, the learning outcome of students having interpersonal intelligence was the same in students having verbal intelligence.

Miftachudin et al. (2015) conducted research in class VII SMP to determine the effectiveness of the TSTS type learning model with peer tutors in learning mathematics on a flat shape material which involves multiple intelligences. From the results, the following were observed: (1) The TSTS learning model with peer tutors resulted in better student outcomes compared to the direct. (2) Students with logical-mathematical, verbal and interpersonal intelligences had the same achievement. (3) In the TSTS learning model with peer tutors, students with logical-mathematical, verbal and interpersonal intelligence had the same student achievement. (4) Students with logical-mathematical intelligence, verbal and

interpersonal intelligence produced better learning achievements compared to the direct learning models.

This type of learning will be susceptible to transmission of the COVID-19 virus. It should be done online, but there will be many obstacles in its implementation. We can use a variety of applications suitable for this type of learning.

Taufik and Adiastuty (2017) conducted a research in class VIII MTs to describe relations and functions in mathematics learning involving multiple intelligences, using a scientific approach. The steps involved 1) preliminary activities; 2) core activities which include observing, asking questions, gathering information, associating and communicating; and 3) conclusion and evaluation. The multiple intelligences involved include verbal/linguistic, visual/spatial, logical/mathematical, musical, bodily/kinesthetic, interpersonal, and intrapersonal. This research is a classroom action research with two cycles in which each cycle consists of four phases. They are planning, action, observation and reflection. Results of each cycle were analyzed on two types; the first type on students and teacher activities and the second type on students learning outcome. The results can be seen in Table 1 and Table 2.

Table 1. *Analyses on Students and Teacher Activities on the Cycles*

Cycle	Activity	Average (%)	Category
I	Students' Activities	70	Poor
	Teacher' Activities	76	Enough
II	Students' Activities	82	Good
	Teacher' Activities	83	Good

Table 2. *Analysis on Students Learning Outcome who Exceed the Passing Grade 75% Correct Answers on the Cycles*

Cycle	Number of Students	Percentage
I	18	46
II	31	80

Therefore, the increase in learning outcome from cycle I to II was 34%. In research, there are several factors that are key to the success of an actionable research finding. First, researchers and educators form different groups. Mixing students with multiple levels of ability will increase resources in a group. Second, researchers reduce teacher education, by providing a broader way for students to analyze, ask questions, explore data from a variety of disciplines, participate, and present work and give presentation groups.

Third, researchers and educators provide students with a variety of ways to solve questions with more complex levels by asking and doing homework, so that students have sufficient knowledge and experience in the use of certain terms. Fourth, researchers and educators provide support to students. Diligence is the key that is required by educators in an effort to improve learning. Creating support for students can do two things: provide support and encouragement.

Aini et al. (2018) conducted an experiment in class VIII SMP to describe students' mathematical literacy in solving math questions about number pattern

problems which involved multiple intelligence. The results showed that students with verbal-linguistic intelligence, logical-mathematical and naturalists have the same tendency to identify concepts, define and determine initial ideas, find relationships between variables, and make mathematical models of problems. However, the indicators used to describe a mathematical situation were different for each intelligence. Verbal-linguistic and logical-mathematical students can write down situations using symbols, but naturalist students cannot. Furthermore, in designing strategies, students having verbal intelligence tend to write down steps with easy-to-understand delivery. Logical-mathematical students formulated steps that produced the right solution, while naturalist students tend to use pictures.

Kurniawati and Kurniasari (2019) conducted a research in class X SMA to describe the mathematical literacy of students with verbal, logical-mathematical and spatial intelligences in solving PISA problems involving space and shape content. The results showed that students with verbal intelligence underwent several processes, namely identifying mathematical aspects of the problem, translating problems into mathematical language, designing strategies to determine solutions (but not entirely accurate), describing the steps for solving problems according to the strategies designed, reinterpreting the results or solutions into the context of real-world problems, and explaining the reasons for the accuracy of the given conclusions. Students with logical-mathematical-intelligence underwent several processes, namely, identifying mathematical aspects of the problem, translating them into mathematical language, designing strategies to determine solutions, describing the steps for determining mathematical solutions in detail, and systematically not reinterpreting the results or solutions obtained into the context of real-world problems, but clarifying the appropriateness of the given conclusion. In addition, subjects with spatial intelligence underwent several processes, namely, identifying mathematical aspects of the problem, translating them into mathematical language, designing strategies to determine solutions, and not reinterpreting the results obtained in the context of real-world problems, but clarifying the appropriateness of the given conclusion.

There should be a set of criteria for research prior to the data retrieval collection process that has been carried out with the aim of correcting the sentences in the research so that they can be well-understood by the research with no misrepresentation. In the math test questions, the researcher should write down the information for each subject to write a conclusion on a given problem or translate the math solution into more applicable meanings of everyday life. Because there are some studies that do not write a conclusion, it is better if the researcher informs the decision to write down the final conclusion of the problem-solving process. In order for these results to be widespread, relevant studies should be carried out so that it can explain students' mathematical literation in solving PISA questions on others topics.

Nugroho and Husni (2020) conducted research in class VIII SMP to determine the learning outcome in the TAI and Jigsaw cooperative learning model involving multiple intelligences. The results showed that: (1) there was a significant difference in learning outcomes in this cooperative learning model before and after treatment; (2) there was no significant difference in outcome

between students having linguistic, logical mathematical, and other types; (3) there was no significant difference in outcome between linguistic, logical-mathematical and others in the implementation of the TAI type learning model; (4) there was no significant difference in learning outcome between students having verbal, logical-mathematical and other intelligences in the implementation of the Jigsaw type learning model; (5) there was a positive, significant difference in learning outcome between the TAI and Jigsaw learning models in students with verbal intelligence.

Students achieve a wide range of multidisciplinary skills including language skills, mathematical skills and other skills. This shows that all types of intelligence of students have similarities in problem solving. This is based on the discovery of a collaborative study of the TAI and Jigsaw modes where there is no difference in the achievement of the same type of learning among the more intelligent students.

The potential of the skills acquired by the students must be considered by the instructor in the field of mathematics in order to develop effectively. Curriculum can be customized according to local circumstances and the abilities of the students.

TAI co-curricular activities enable students to assist in the design of instruction for peer-to-peer learning, so that the learning of students with good language skills can be improved and their math skills improved as well.

Conclusions

From the research results, the following conclusions were obtained:

1. Students with verbal intelligence are suitable for peer tutoring and independent learning models with e-learning, Two Stay Two Stray with peer tutors, TAI and Jigsaw.
2. Students with logical-mathematical intelligence are suitable for the STAD and TGT, GI and NHT learning models, Two Stay Two Stray with peer tutors, TSTS and NHT.
3. Students with kinesthetic intelligence are suitable for the STAD and TGT learning models,
4. Students with interpersonal intelligence are suitable for the STAD and TGT learning models, peer tutoring and independent e-learning, Two Stay Two Stray with peer tutors, TSTS and NHT able should be editable and must be at an appropriate place in the main text such as figures. For the tables, use the following format.

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